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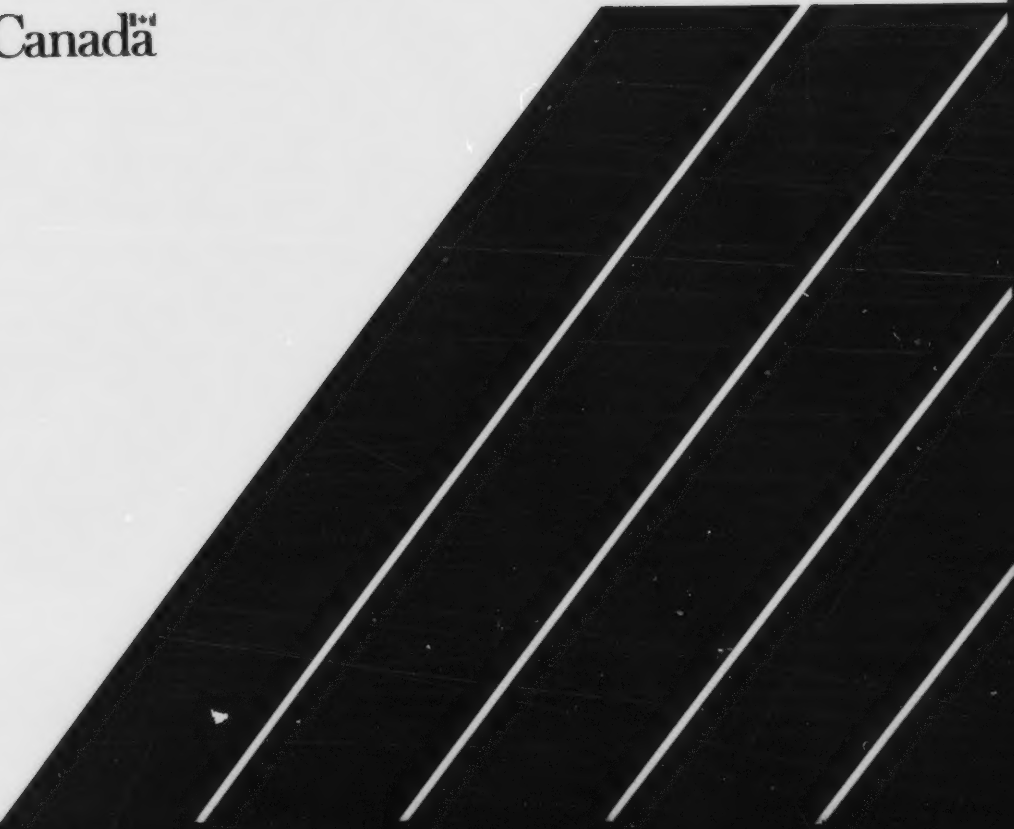

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TECHNOLOGY REVIEW REPORT ON PHOTOVOLTAIC-POWERED WATER PUMPING

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PREFACE

This Report is a summary of the current technical status of Photovoltaic powered water pumping technology and its applications. It is intended to provide background information to Canadian industry and potential users to assess opportunities for participating in this market. It builds heavily on the work of other reports and technical papers in order to provide a broad overview of the technology.

In addition, it is intended to provide a background paper for the Energy, Mines and Resources personnel to assist in planning future work in the field.

ABSTRACT

This is a technical review report on Photovoltaic Powered Water Pumping Technology. It summarizes the most recent technical and economic reports presented at recent conferences and the most current opinions of internationally acknowledged experts in the field. It details current economics of PV water pumping relative to diesel, wind, and hand powered systems. Potential markets are explored along with projected pricing of system costs.

It provides a broad spectrum of background material for the PV pumping technology with specific cost data for comparative assessment.

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EXECUTIVE SUMMARY

The purpose of this report is to present the current state of the technology of Photovoltaic powered water pumping throughout the world. A second follow on report to this one will detail the Canadian capability to participate in this world market by Canada's industrial, commercial and engineering sectors.

The focus will be on the application of village water pumping for humans and livestock although irrigation and other applications will also be discussed. It is a summary of many published documents, research literature and reports produced by many authoritative sources throughout the world.

The ten years from 1981 to 1990 have been designated by the United Nations as the "International Drinking Water Supply and Sanitation Decade". Despite this programme there are still nearly 1000 million people living without access to a safe and reliable supply of water. The potential market is obvious, however the more critical question is endeavouring to identify means of providing the dollar resources needed to convert the potential market to an actual market.

The Canadian International Development Agency (CIDA) is one of the international funding agencies who is currently viewing PV water pumping systems as an attractive option in assisting developing countries in their economic and social development.

Canada has applications of PV water pumping systems but these are limited in number.

This report reviews the PV pumping technology, the current hardware being used, the economics of the technology and discusses some trends and general conclusions.

Technically, PV power systems are capable of supplying appropriate power to any pumping system with appropriate design. Practical and economic considerations under today's conditions, however, restrict the range of applications to primarily potable water pumping and certain irrigation applications.

PV water pumping is different from other water pumping because of the daily variation in the electrical power available from the solar array to power the pump. Unless batteries are used, daylight pumping only is utilized. The high cost of electrical power places a great emphasis on the need for energy efficient equipment in the pumping system over the range of power levels produced. As DC power is what the array produces, it is generally more desirable to power the pumps with DC motors.

The major components of the pumping system are the array, the power conditioner/control, the pump motor and the pump. These are interfaced in five major configurations found in current applications.

Four general classifications of head/volume systems have been developed by the World Bank which cover total heads of 2, 7, 20 and 40 metres with volumes of 60, 60, 20 and 40 cubic metres per day output respectively.

A descriptive term of "metres to the forth (m4)" has been developed to describe the approximate power required for a pumping system. A figure is obtained by multiplying the volume in cubic metres per day by the total head in meters. A system of 400 metres to the forth would be roughly half the size of a system of 800 metres to the forth.

Nomographs are presented for assistance in a manual design process for PV water pumping.

The principal configurations of solar pumps are:

Type A - submerged pump and motor
Type B - submerged pump, surface mounted motor, rotary drive shaft
Type C - submerged pump cylinder, surface motor, reciprocating drive shaft
Type D - floating motor and pump
Type E - surface mounted pump and motor - suction feed from the water

Electric drives for PV pumps use both DC and AC power. While DC voltages range from 12 to 180 volts, the AC systems are generally designed to operate at conventional 110, 220 or 240 volts.

DC motors are attractive as this is the form of power

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delivered by the array. An electrical interface and control strategy called "a maximum power tracker (MPT)" is designed to optimize the power developed by the array for driving the motor. Although slightly more efficient than AC motors, DC motors are generally more expensive and traditionally require replacement of brushes at periodic intervals. New brushless type DC motors are now available in many sizes which are electronically commutated and are becoming more attractive as their reliability improves. There is a need for a good submersible brushless DC motor pump set and at least one manufacturer is currently conducting field trials.

AC motors utilized in PV pumping systems require either a storage battery to stabilize voltage to a conventional inverter or alternatively a special type of converter which changes the varying DC current into a variable frquency variable voltage output power which the AC motor can accept. The special inverter is the type used on the most popular motor/pump set produced by the international pump manufacturer, Grundfos Pumps.

Innovative pump types are discussed, two of which are Canadian designs. The Ergo Pump has a submerged DC brushless type motor driving a positive displacement type reciprocating piston pump, all of which is designed to fit in a 6" bore hole. Manufacturers performance data is presented but field test results are not available.

The Pulsa water oscillation pump utilizes compressable spheres of tennis ball size in a submerged pump chamber. These store energy during the compression stroke and deliver water up the delivery pipe on the delivery stroke. No field test results are available on this unit as well.

A submerged progressive cavity type pump utilizing an adaption of the "Archimedean Screw Principle" has demonstrated very good efficiencies. Peter Ward & Associates of British Columbia are integrating a DC sealed motor with the drive portion of the progressive cavity pump so that the entire pump motor set can be submerged as with the submerged multistage centrifugal (SMC) pumps.

In testing the efficiencies of pumps and pump sets, "standard days" were developed by the IT Power/Halcrow team in 1983 during the World Bank project. These represent solar irradiation totals of 4, 5 and 6 kilowatt hours per metre squared over a full day. Integration of the output of pump sets over hourly periods with constant specified irradiances, produced comparable daily pump output figures. The concept of "specific capital cost (SCC)" was also developed which is a useful method to measure the cost value of PV pumping systems to one another by considering the efficiency of the equipment as well as the cost. Essentially it relates the capital cost of the system to the amount of water delivered over a daily period. For comparing PV pumping systems to other forms of power generation, however, life cycle costing should be utilized.

While no specific standards have as yet been issued for PV pumps or PV pumping systems, identified standards by recognized bodies are listed which are currently used for testing various types of pumps.

Approximately 6000 PV pumping installations are currently estimated to be operationaly throughout the world ranging from very small 1 or 2 module installations to a 70 kilowatt installation in Italy at Zambelli.

The distribution of these PV pumping systems at the end of 1988 is estimated to be as follows:

Africa	-	2000
Australasia	-	1300
Latin America/Caribbean	-	600
Canada	-	35
India	-	600
U.S.	-	500
Asia	-	850
Other	-	115
Total	-	6000

Approximately 35 PV powered pump installations have been identified installed in Canada with the majority being small systems for domestic water supplies at remote residences and stock watering installations in the Prairies.

A number of international PV pumping projects are listed and detailed reports are included in the Appendices.

The major participants in the PV water pumping industry include the major PV module manufacturers and a number

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of system houses who specialize in design and supply of PV power systems to third parties. A number of pump manufacturers have produced specific products for PV pumping systems and a number of these are listed. A list of ground water industry major conferences and meetings dealing with various aspects of ground water is given for 1988 and 1989.

PV water pumping programmes of 3 aid agencies are reviewed including the Canadian International Development Agency (CIDA), the European Economic Community and Mali Aqua Viva. 1988 prices for PV pumping systems are listed indicating a range of cost from $7.00 to $15.00 per peak watt with the larger array sizes having lower costs per peak watt.

Various tables are presented giving the present and projected costs of solar pumps. Included also is a list of detailed quotations received in response to a major 1985 enquiry.

PV solar pumps are compared to diesel pumps for competitiveness and it is estimated that solar pumps are typically cost competitive compared with diesels for rural water supply applications up to approximately 800 m4 per day capacity. In areas of high diesel pump operating costs, solar pumps can be competitive up to 2500 m4.

For irrigation, solar pumps are currently only cost effective up to approximately 250 metres to the forth per day capacity.

It is anticipated that decreasing costs of arrays provide potential for costs to fall to an installed cost of approximately $5.00 to $9.00 per watt peak by 1996.

The stainless steel multistage submersible pump as manufactured by Grundfos Pumps which is an AC driven unit, has been emerging as a preferred unit by a number of organizations.

A recognition of the need for not only pumping water in village applications but the need for treatment of that water to a clean and healthy condition is expanding the scope of the pumping system design to include filtration and other forms of treatment.

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R and D work is progressing on developing AC controller/inverters to interface solar arrays with submerged AC pump motors. Other groups are working on eliminating the long surface to water power shaft on progressive cavity rotary positive displacement pumps in order to take advantage of the higher pumping efficiency of these units. A Canadian group is working on DC motors while a German group is working on the submersible AC type.

It is recognized that most village PV pumping systems will be installed with the help of international foreign aid money and that in many programmes, commercial strings will be tied to restrict the bidders to the donors trade resources where possible. A need for joint ventures is forseen.

A vast long term market potential exists in south east Asia where literally millions of small farmers rely on irrigation for their small land holdings. A small low cost PV system if competitive will penetrate this market.

A recent report by Meridian Corporation indicates a potential market of 194,000 villages appropriate for PV systems worldwide which would average 1453 watt peak in array size.

The solar to hydraulic efficiency of current PV pumping systems is generally in the 4 per cent range with array efficiencies of 12 per cent and pump motor set efficiencies in the 30 to 40 per cent range. There is currently throughout the world an international technology base of equipment suppliers and systems houses able to provide reliable equipment and systems for photovoltaic powered water pumping systems.

There is also a growing recognition of the benefits of including PV pumping technology as a component of national renewable energy programmes.

Several recommendations are given including identifying aid groups who have the potential or are involved in funding PV water systems, evaluating the relative merits of computer simulation models and encouraging the support of R and D in the technical development of controls, DC submersible motors, motor efficiency and independent field trials of testing with appropriate monitoring.

RÉSUMÉ

Le présent rapport décrit l'état actuel de la technologie des pompes à eau alimentées à l'énergie photovoltaïque dans le monde entier. Un rapport complémentaire examinera, en détail, la capacité des secteurs canadiens de l'industrie, du commerce et du génie de tirer profit des débouchés internationaux dans ce domaine.

Bien que l'exposé qui suit traite brièvement d'irrigation et d'autres usages, il porte surtout sur le pompage de l'eau destinée à la consommation humaine et à l'abreuvement du bétail dans les villages. Il s'agit d'une récapitulation de nombreux documents, rapports de recherche et autres écrits d'organismes d'un peu partout dans le monde qui font autorité en la matière.

La période de 1981 à 1990 a été désignée par les Nations Unies comme la "Décennie internationale de l'eau potable et de l'assainissement". Toutefois, malgré l'existence de ce programme, il y a encore près d'un milliard de personnes qui n'ont pas accès à un approvisionnement d'eau sûr et fiable. Les possibilités commerciales sont évidentes; ce qui est plus difficile, c'est de trouver les moyens financiers pour faire se concrétiser les débouchés qu'elles représentent.

L'Agence canadienne de développement international (ACDI) est l'une des agences de financement international qui voient à l'heure actuelle dans les systèmes de pompage d'eau à alimentation photovoltaïque un moyen attrayant d'aider à l'avancement social et économique des pays en développement.

Il y a des systèmes de pompage d'eau à alimentation photovoltaïque en exploitation au Canada, mais ils ne sont pas nombreux.

Le présent rapport examine les techniques de pompage à alimentation photovoltaïque, ainsi que le matériel employé à l'heure actuelle et l'économique de ces techniques. Il fait aussi état de certaines des tendances relevées et en tire des conclusions générales.

Au plan technique, le système photovoltaïque peut, s'il est bien conçu, fournir assez d'énergie pour alimenter n'importe quel système de pompage. Des considérations pratiques et économiques imposées par la conjoncture en limitent toutefois l'usage au pompage de l'eau potable surtout et à certaines formes d'irrigation.

Le pompage de l'eau à l'aide d'énergie photovoltaïque diffère de toutes les autres techniques de pompage, en raison des variations quotidiennes de l'énergie électrique fournie à la pompe par le champ photovoltaïque. A moins que l'installation ne soit équipée d'accumulateurs, le pompage

ne peut s'effectuer que pendant la journée. Par ailleurs, étant donné le coût élevé de l'électricité, il est très important d'employer pour le système de pompage du matériel qui donnera un bon rendement énergétique pour la gamme entière des puissances produites. Comme le champ photovoltaïque produit l'électricité sous forme de courant continu, il est donc, en règle générale, préférable d'utiliser aussi un moteur à courant continu pour actionner la pompe.

Les principaux éléments du système de pompage sont le champ photovoltaïque, le dispositif de commande et de conditionnement de l'alimentation, le moteur de la pompe et la pompe elle-même. On relève essentiellement cinq façons de raccorder ces éléments dans les systèmes en usage à l'heure actuelle.

La Banque mondiale a réparti les systèmes en quatre catégories, d'après leur caractéristique hauteur manométrique totale en fonction du débit. Ainsi, on a des pompes à hauteur manométrique totale de 2, 7, 20 et 40 mètres (m) fournissant respectivement un débit de 60, 60, 20 et 40 mètres cube par jour (m^3/j).

On parle par ailleurs de "mètres puissance 4 (m^4)" pour désigner la puissance approximative qu'exige un système de pompage. Cette donnée est le produit du débit (m^3/j) par la hauteur manométrique totale (m). Par exemple, un système de 400 m^4 exige à peu près la moitié de la puissance d'un système de 800 m^4.

Les abaques inclus dans le rapport faciliteront la conception manuelle de systèmes de pompage d'eau à alimentation photovoltaïque.

Les principaux types de pompes solaires sont les suivants :

Type A - groupe électropompe immergé
Type B - pompe immergée, moteur monté en surface et arbre d'entraînement à mouvement rotatif
Type C - cylindre de pompe immergé, moteur monté en surface, arbre d'entraînement à mouvement alternatif
Type D - groupe électropompe flottant
Type E - groupe électropompe monté en surface avec conduite d'admission par aspiration

Les commandes électriques des pompes à alimentation photovoltaïque fonctionnent sur courant continu ou courant alternatif. La tension des systèmes à courant continu varie de 12 V à 180 V, alors que celle des systèmes à courant

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alternatif s'établit habituellement à l'une des valeurs classiques, soit 110 V, 220 V ou 240 V.

Les moteurs à courant continu sont particulièrement attrayants, car ils emploient la forme d'énergie que livre le champ photovoltaïque. Une méthode de commande et d'interface électrique, dite "de recherche de puissance maximale", permet d'optimiser la puissance produite par le champ photovoltaïque pour alimenter le moteur. Bien que les moteurs à courant continu soient un peu plus efficaces que les moteurs à courant alternatif, ils sont aussi, en général, plus coûteux. De plus, il fallait, jusqu'ici, en remplacer régulièrement les balais. Toutefois, il existe maintenant de nouveaux modèles de puissances variées qui n'ont pas de balais et sont commutés électroniquement. Ces modèles deviennent plus attrayants à mesure que s'améliore leur fiabilité. Un bon groupe électropompe immergé, à courant continu et sans balais, trouverait certes des preneurs, et au moins un fabricant a commencé à en faire l'essai.

L'intégration d'un moteur à courant alternatif à un système de pompage à alimentation photovoltaïque oblige à employer une batterie d'accumulateurs pour stabiliser la tension fournie à un onduleur classique, à moins qu'on ne substitue à celui-ci un convertisseur spécial qui transforme le courant continu changeant en une puissance de sortie à tension et fréquence variables convenant à ce type de moteur. Le fabricant international Grundfos Pumps a opté pour cette dernière solution pour son modèle de groupe électropompe le plus populaire.

Le rapport renferme aussi la description de modèles de pompe novateurs, dont deux sont de conception canadienne. La pompe Ergo comporte un moteur à courant continu sans balais, qui est immergé et actionne une pompe volumétrique à piston alternatif. Le groupe électropompe entier est conçu pour s'adapter à un trou de 6 po de diamètre. Le rapport fait mention des rendements allégués par les fabricants, mais les résultats des essais pratiques de ces systèmes ne sont pas encore connus.

La pompe à oscillations de marque Pulsa fait appel à des billes compressibles, de la taille d'une balle de tennis, qui sont placées dans la chambre de la pompe immergée. Ces billes emmagasinent l'énergie pendant le temps de compression et amènent l'eau à la conduite de refoulement pendant le temps de refoulement. Aucun résultat d'essais pratiques n'a encore été publié au sujet de cette pompe.

Une autre pompe immergée qui emploie une variante du principe de la vis sans fin pour faire se déplacer un volume fermé dans son cylindre a donné de très bons résultats. La firme

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Peter Ward & Associates de Colombie-Britannique s'efforce à l'heure actuelle d'intégrer un moteur étanche à courant continu à son entraînement, afin de pouvoir immerger le groupe entier, comme s'il s'agissait d'une pompe centrifuge multicellulaire immergée.

L'équipe IT Power-Halcrow a élaboré le concept du "jour standard", lorsqu'elle a expérimenté le rendement de divers modèles de pompes et groupes électropompes pour la Banque mondiale en 1983. Elle désigne par cette expression une irradiation totale de 4, 5 ou 6 kilowattheures du mètre carré pendant une journée entière ($kWh/m^2/j$). L'intégration d'une valeur constante d'irradiation spécifique au calcul du débit horaire de divers groupes électropompes a permis d'en comparer le débit quotidien. Le "coût précis en capital" est un autre concept nouveau d'une grande utilité pour comparer le prix de revient des divers systèmes de pompage à alimentation photovoltaïque, car il tient compte du rendement du matériel aussi bien que de son coût. Essentiellement, il établit une corrélation entre le coût en capital du système et la quantité d'eau débitée en une journée. Toute comparaison des systèmes de pompage à alimentation photovoltaïque aux systèmes employant une autre forme d'alimentation devrait néanmoins se fonder sur le prix de revient pour la durée utile.

Bien qu'aucune norme précise n'ait encore été publiée à l'égard des pompes ou systèmes de pompage à alimentation photovoltaïque, le rapport fait mention des normes qu'emploient à l'heure actuelle des organismes reconnus pour faire l'essai de divers types de pompes.

On estime qu'il y a aujourd'hui à peu près 6 000 installations de pompage à alimentation photovoltaïque en exploitation dans le monde entier. Ces installations vont du petit système à un ou deux modules au groupe de 70 kW en exploitation à Zambelli, en Italie. A la fin de 1988, elles se répartissaient comme suit :

Afrique	-	2 000
Australasie	-	1 300
Amérique latine et Antilles	-	600
Canada	-	35
Inde	-	600
États-Unis	-	500
Asie	-	850
Autre	-	115
Total		6 000

On dénombre à peu près 35 installations de pompage à alimentation photovoltaïque en exploitation au Canada. La plupart sont de petits systèmes de pompage d'eau de

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consommation approvisionnant des habitations reculées ou servant à abreuver le bétail dans les Prairies.

Il est en outre fait mention de divers projets internationaux de pompage à alimentation photovoltaïque, dont il se trouve une description détaillée en annexe.

Les principaux éléments de l'industrie de pompage d'eau à alimentation photovoltaïque sont les grands fabricants de modules photovoltaïques et divers constructeurs de systèmes se spécialisant dans la conception et l'installation de systèmes d'alimentation photovoltaïque pour des tiers. Un certain nombre de fabricants de pompes ont en outre mis en marché des produits précis convenant aux systèmes de pompage à alimentation photovoltaïque. Quelques-uns de ces produits sont mentionnés ici. Le rapport offre également un calendrier des principales rencontres et conférences devant avoir lieu en 1988 et 1989 où l'on traitera de divers aspects de la mise en valeur des eaux souterraines.

On passe ensuite en revue les programmes de pompage d'eau à alimentation photovoltaïque de trois organismes d'entraide, à savoir l'Agence canadienne de développement international (ACDI), la Communauté économique européenne et l'agence Mali Aqua Viva. Un examen du prix courant des systèmes de pompage à alimentation photovoltaïque en 1988 permet par ailleurs de constater que le coût de cette technique de pompage varie de 7 $ à 15 $ du watt-crête et diminue avec l'agrandissement du champ photovoltaïque.

Divers tableaux indiquent le coût actuel et prévu des pompes à énergie solaire. Ils se complètent d'une liste de prix détaillée, compilée à la suite d'une importante enquête menée en 1985.

Une comparaison des pompes à alimentation photovoltaïque aux pompes au diesel permet par ailleurs de constater que les premières peuvent habituellement se substituer avantageusement aux secondes pour l'approvisionnement d'eau en milieu rural, jusqu'à concurrence d'une capacité de 800 m^4/j environ. Dans les régions où l'emploi d'une pompe au diesel est coûteux, l'utilisation d'une pompe à énergie solaire peut s'avérer concurrentielle jusqu'à une capacité de 2 500 m^4/j. Elle n'est par contre pas encore rentable pour l'irrigation, si on a besoin d'une capacité supérieure à 250 m^4/j environ.

On s'attend néanmoins que son coût baisse avec celui des champs photovoltaïques, pour s'établir d'ici 1996 entre 5 $ et 9 $ environ, selon la puissance de crête désirée.

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La pompe multicellulaire immersible en acier inoxydable, du type fabriqué par Grundfos Pumps, qui est actionnée par un moteur à courant alternatif est en passe de devenir l'appareil préféré d'un certain nombre d'organismes.

Par ailleurs, comme on se rend compte qu'il ne suffit pas de pomper l'eau dans les villages, mais qu'il faut aussi traiter cette eau pour l'assainir, la conception des systèmes de pompage évolue graduellement vers l'intégration de mécanismes de filtrage et de diverses autres formes de traitement.

On fait à l'heure actuelle des recherches pour mettre au point un onduleur-graduateur pour courant alternatif qui permettrait de raccorder un champ photovoltaïque à un groupe électropompe à courant alternatif immergé. Des chercheurs s'efforcent aussi de trouver un moyen de supprimer le long arbre d'entraînement que comportent (entre la surface et l'eau) les pompes à mouvement rotatif et volume fermé en déplacement, afin de tirer profit du rendement supérieur de ces appareils. Enfin, un groupe de chercheurs canadiens expérimente des moteurs à courant continu, et un groupe allemand travaille à mettre au point un moteur à courant alternatif immersible.

On reconnaît que la plupart des systèmes de pompage à alimentation photovoltaïque de village seront installés grâce à l'appui financier d'organismes d'entraide internationaux et que, dans bien des cas, l'aide apportée sera assujettie à des conditions astreignant les soumissionnaires à utiliser le plus possible les ressources commerciales des donateurs. On prévoit donc la nécessité d'entreprises de collaboration.

Il existe de vastes débouchés à long terme dans le sud-est de l'Asie où, littéralement, des millions de petits agriculteurs dépendent de l'irrigation pour exploiter leurs terres. S'il était compétitif, un petit système photovoltaïque à prix modeste pourrait pénétrer ce marché.

Il ressort d'un rapport publié récemment par la Meridian Corporation qu'il y a dans le monde possiblement 194 000 villages auxquels conviendrait un système photovoltaïque. La puissance de crête du champ photovoltaïque requis serait en moyenne de 1 453 W.

Le rapport de l'énergie solaire utilisée à la quantité d'eau refoulée des systèmes de pompage à alimentation photovoltaïque en marché à l'heure actuelle est habituellement de 4 % environ, le rendement du champ photovoltaïque étant de 12 % et celui du groupe électropompe de 30 % à 40 %. Il y a présentement dans le monde un noyau international de fournisseurs d'équipement et de constructeurs de systèmes capables de fournir du matériel et

...Résumé/

des systèmes sûrs pour l'installation de systèmes de pompage d'eau à alimentation photovoltaïque.

On reconnaît par ailleurs de plus en plus les avantages de l'intégration des techniques de pompage à alimentation photovoltaïque dans les programmes nationaux d'exploitation des énergies renouvelables.

Le rapport se termine sur quelques recommandations; on suggère, entre autres choses, de repérer les groupes d'entraide qui ont la possibilité de financer ou financent déjà des systèmes de pompage d'eau à alimentation photovoltaïque, d'évaluer les mérites relatifs de modèles de simulation informatisée et d'encourager l'appui des travaux de recherche et de développement dans le domaine du perfectionnement technique des commandes, des moteurs à courant continu immersibles, du rendement des moteurs et de l'exécution d'essais pratiques indépendants, adéquatement surveillés.

...Résumé/

1.0 - INTRODUCTION

The ten years from 1981 to 1990 have been designated by the United Nations as the "International Drinking Water Supply & Sanitation Decade". (1) The target of the program is to provide safe drinking water and sanitation to all rural and urban populations of the world yet more than three quarters through that decade, there still are nearly one thousand million people living without access to a safe and reliable supply of water.(2) There are many problems to be surmounted before the goal is reached with the main ones being identified as the technical performance and reliability of rural water supplies systems, the lack of adequate infrastructure to support the systems, and ultimately the costs of such systems.

In addressing the issues of technical performance and reliability, the photovoltaic technology is seen as a most appropriate application. By converting the sun light directly into electricity thus powering electrified pumps, most of the desired characteristics are developed for these remote systems. The conversion process itself is benign and environmentally ideal while being capable of running essentially unattended and with a minimum of maintenance. The reliability of photovoltaic power pumping systems is extremely high and accepted throughout the third world as a most desirable form of energy. While hand pumps, photovoltaics and diesel water pumping technologies all have their place in achieving the aspiration of the United Nations program, the constantly decreasing costs of photovoltaic modules is expanding the role that the photovoltaic system can play by becoming more and more competetive with the competing technologies such as wind, and diesel.

It has been estimated that the cost of meeting the world's current needs for clean water alone is in excess of ninety billion dollars U.S.(2) based on a mix of all current technologies.

The purpose of this report is to present the current state of the technology of photovoltaic powered water pumping throughout the world. A second follow on to this one report will detail the Canadian capability to participate in this world market by Canada's industrial, commercial and engineering sectors. Providing potable drinking water to humans is not the only valid application of PV pumping but, as the near term market is seen to be primarily in the area village water pumping for humans and livestock, the focus will be on this application. Irrigation and other applications will also be discussed. This report is a summary of many published documents, research literature and reports produced by many authoritative sources throughout the world. Special acknowledgement is given to IT Power Limited of the United Kingdom whose personnel have consulted on this report and contributed greatly in the assembly of research data. IT Power Limited produced the classic report on PV water pumping for the World Bank in 1983,(3) updated it in 1986 (4) and have become one of the world's foremost centres of PV water pumping technology.

There is undoubtedly an urgent and extreme need particularily in the third world for utilizing the PV water pumping technology. The potential market is obvious, however the more critical question is endeavouring to identify a means of providing the dollar resources needed to convert the potential market to an actual market. The bulk of existing installations to-day have been paid for by international aid agencies and a high percentage of near term future installations will also be funded by international aid groups.

The Canadian International Development Agency (CIDA) is one of those funding agencies which is viewing PV water pumping systems as an attractive option in assisting developing countries in their economic and social development. Canada has a photovoltaic industry which is becoming more and more technically competent and able to supply PV systems for all applications including water pumping. This country has an extensive industrial base for manufacturing pumps of all sorts with a listing in excess of one hundred and fifty manufacturers of various types. Many of these types are for specialized applications such as the oil industry, chemical feed pumps, swimming pools, industrial, commercial and residential applications. A large ground water industry exists which creates, maintains, and services wells throughout Canada supplying rural residences, industries, as well as entire communities.

Electric motors to power pumps are produced in abundance within Canada's manufacturing sector and compliment the production of the pumps themselves.

How well this industrial base is able to participate in the growing market in the international arena for the application of photovoltaic water pumping systems will depend on a large number of factors. This report is intended to describe the present technology's status and essentially describe the hardware required for effective reliable and cost effective photovoltaic powered pumping systems. A second report will analyze the capability of Canada's industrial, commercial and engineering sectors to participate in this technology and its development.

Canada itself has applications of photovoltaic water pumping systems, but these are not great in number due to the extensive utility grid network, the ready availability and relatively low cost of diesel engines and fuel combined with the multitude of lakes and rivers as a source of fresh water.

This report will look at the current hardware being used most successfully for PV water pumping and the applications both in Canada and abroad. The economics of the technology will be reviewed and translated into trends and potential markets. Finally some preliminary conclusions will be presented on this technology and some recommendations for it's development.

Unless otherwise stated, all dollar figures in this report will refer to U.S.dollars.

2.0 - DESCRIPTION OF TECHNOLOGY

2.1 - GENERAL

Technically speaking photovoltaic technology is capable of providing electrical power for all types of pump applications. In actual practice they range from small 1/8 horsepower pumps for solar domestic hot water systems to the 70 kw system pumping water for an Italian village in the Alps. Economic considerations, due to relative cost and grid availability, however, effectively restrict practical applications to those remote systems where grid power is not available, servicing is difficult and fuel is expensive. These practical applications include potable water for third world villages and livestock, and irrigation as the next major application. Other applications being developed include active solar domestic water systems, fish farms, desalination systems, water treatment of polluted water sources, lake oxidation, ornamental displays and household use.

The current and near term major use is for potable water pumping for remote villages and livestock while the major long term application is seen to be in the smaller portable irrigation units for the millions of small Asian farmers. (Figure 2.1-1 illustrates a solar pump system for a village water supply.)

Differences

Why is photovoltaic water pumping different from any other water pumping?

First, in considering the pump portion of the system, the power output of the PV array varies over the daily solar cycle hence forcing the pump to run at varying speeds and efficiencies not at its optimum. Also the pump in a PV system will normally run only during the sunlight hours and thus is an intermitent type operation compared to many traditional applications. The efficiency of the pump itself is of far more concern in the PV application due to the relatively high cost of the energy produced by the PV modules. As it is the remoteness of the application that makes the PV system competitive, the need for reliability is increased and thus reliability of pump hardware is paramount as is the need for minimum maintenance and simple servicing.

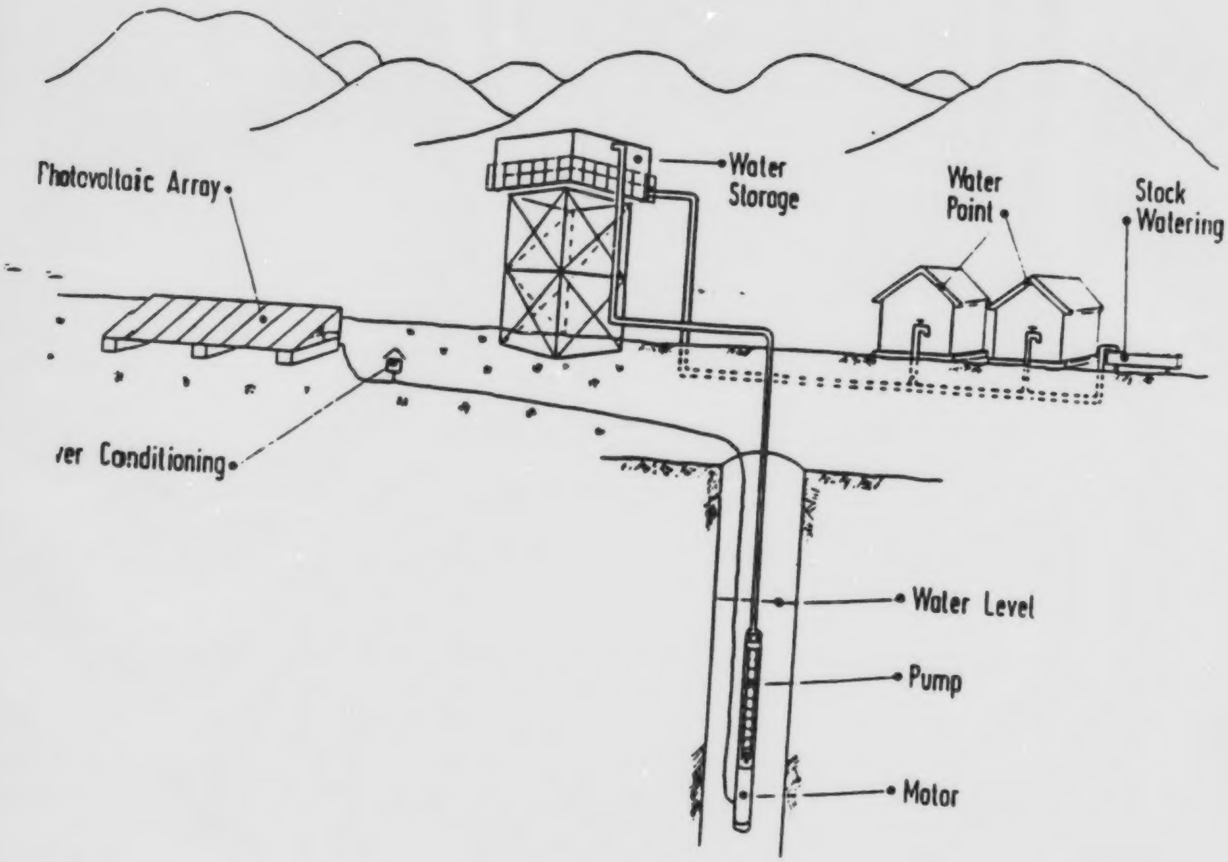

Photovoltaic Array
Water Storage
Water Point
Stock Watering
ver Conditioning
Water Level
Pump
Motor

FIGURE 2.1-1

SCHEMATIC OF A SOLAR PUMP FOR VILLAGE WATER SUPPLY

The sizing of the pump is somewhat more critical than a conventional application as the run time of the pump is limited while over sizing may create problems of it's own in lost efficiency and excessive draw down of the water level.

An additional consideration in the PV technology is the practical consideration of utilizing direct current motors for the pump source as opposed to alternating current in order to simplify the interface between the solar source and the pump motor.

All of these characteristics impact on the cost of the pump unit which in normal commercial operations may not be warranted. In the case of a solar application the additional cost required to improve efficiency etc. could well be justified.

From the PV side of the system a major difference from most stand alone systems is the lack of energy storage by means of batteries. This difference is due to the general concensus that storing the pumped water as a product storage is more economical than storing the energy as electro-chemical energy in traditional batteries. Over designing the PV element can create problems in excessive draw down of the water levels as well as the obvious penalty for the initial cost. The water load or output of the system is somewhat less defineable as the availability of water in many cases automatically increases the use of the water in some areas, plus the number of people who wish to utilize it.

Finally.in the water pumping application the load in the form of the electric pump is integrated into the system design more closely due to the interactive nature of the pump efficiencies with the electrical power characteristics.

The PV pumping system thus has special attributes which must be addressed as design considerations in order to provide an optimized PV pumping system.

System Components

The major components of a basic PV pumping system are:

a) The solar array

b) The power conditioner/control

c) The pump motor

d) The pump

A block diagram of a PV-Powered water pumping system is shown in Figure 2.1-2.

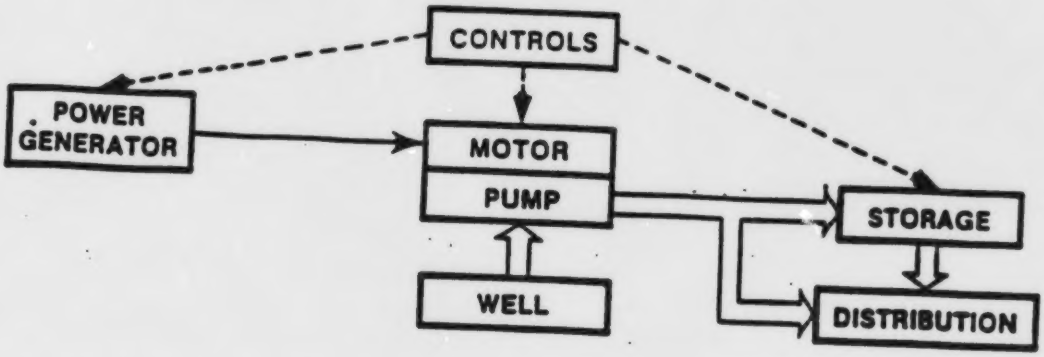


FIGURE 2.1-2

BLOCK DIAGRAM OF PV-POWERED WATER PUMPING SYSTEM

The "controls" as indicated by the dotted line are optional and for most systems manual intervention controls and alarms are not normally fitted. Types of controls can include dry running protection systems. Distribution includes field application in irrigation systems (i.e. drip irrigation systems).

A complete pumping system powered by photovoltaics can comprise the following if located in a remote location:

- security (fences)
- well (drilled or hand dug)
- pump foundations or supports
- storage
- piping from water to storage
- distribution piping from storage
- alarms
- cabling
- enclosures
- switches
- spares
- water treatment optional
- maintenance program
- performance monitoring

The above components are in addition to the basic array, motor pump and control components.

The terminology used to describe the system hydraulics is given in Figure 2.1-3a and Figure 2.1-3b.

System Classification

While there are many ways of classifying PV water pumping systems, i.e. volume, head, type of pump, etc. the pumping application itself has been classified in the following four general categories through the work on the World Bank report by Halcrow (3). These four groupings are listed below in Table 2.1-1 where the volume is expressed in cubic metres per day as well as U.S. gallons per hour.

Type	Volume Required/ Approx.		Total Head		Application
	cu.m/day	U.S.Gal./Hr.	in m.	in ft.	
A	60	3166	2	6.5	irrigation
B	60	3166	7	23	open & dug wells for village water
C	20	1056	20	65	village water
D	40	2112	40	132	larger villages & deep wells

TABLE 2.1-1
FOUR PV PUMPING CATEGORIES

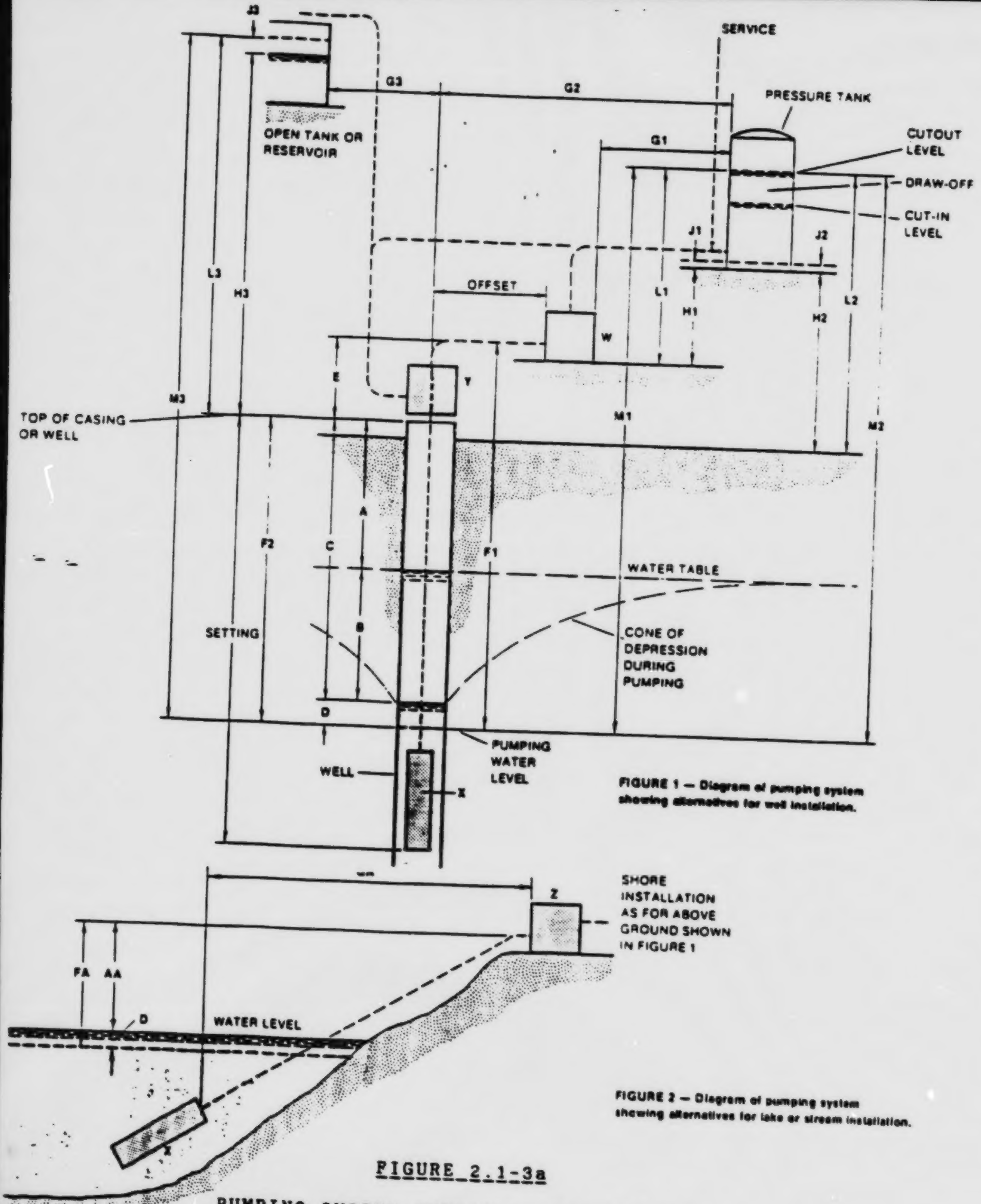

J3
SERVICE
G3
G2
PRESSURE TANK
OPEN TANK OR
RESERVOIR
G1
CUTOUT
LEVEL
DRAW-OFF
CUT-IN
LEVEL
J1
J2
L3
H3
OFFSET
L1
H1
H2
L2
W
E
Y
M3
TOP OF CASING
OR WELL
M1
M2
A
F2
C
F1
WATER TABLE
B
SETTING
CONE OF
DEPRESSION
DURING
PUMPING
D
PUMPING
WATER
LEVEL
WELL
X
Z
SHORE
INSTALLATION
AS FOR ABOVE
GROUND SHOWN
IN FIGURE 1
FA
AA
D
WATER LEVEL
X

FIGURE 1 — Diagram of pumping system showing alternatives for well installation.

FIGURE 2 — Diagram of pumping system showing alternatives for lake or stream installation.

FIGURE 2.1-3a

PUMPING SYSTEM HYDRAULIC TERMINOLOGY

A	**STATIC WATER LEVEL** — vertical distance from top of well to natural water level (water table)
AA	**STATIC WATER LEVEL** — vertical distance from shore installation to lowest seasonal water level
B	**DRAW-DOWN** — reduction in water level during continuous pumping at required rate
C	**PUMPING WATER LEVEL** — C = A + B (in case of well)
(1)	Use a shallow-well pump if C is less than 20 feet or 6.0 metres
(2)	Use either a shallow-well or a deep-well pump if C is between 20 and 25 feet or 6.0 and 7.5 metres
(3)	A deep-well pump is essential if C is more than 25 feet or 7.5 metres
D	**FRICTION LOSSES** — expressed as additional depth to water
(1)	In suction system of shallow-well pump
(2)	In offset pipes of deep-well jet pump
(3)	In riser pipe between submersible pump and wellhead
(4)	In column between bowl assembly and discharge head of turbine pump
E	**ELEVATION OF PUMP** above top of well — applies only to shallow-well pump or deep-well jet pump
FA	**TOTAL LIFT TO PUMP** for shallow-well pump or deep-well pump (lake or stream installation) — F = AA + D
F1	**TOTAL LIFT TO PUMP** for shallow-well pump or deep-well jet pump — F1 = C + D + E. Refers to **TOTAL SUCTION LIFT** in performance table for shallow-well pump, or **LIFT, OR DEPTH TO PUMPING WATER LEVEL** in performance table for deep-well jet pump.
F2	**TOTAL LIFT TO TOP OF WELL** for submersible or turbine deep-well pump — F2 = C + D Corresponds to **DEPTH TO WATER LEVEL** in performance table for submersible deep-well pump.
GA	**HORIZONTAL DISTANCE FROM SHORE INSTALLATION** (for lake or stream installation).
G1	**HORIZONTAL DISTANCE BETWEEN PUMP AND PRESSURE TANK** for shallow-well pump or deep-well jet pump
G2	**HORIZONTAL DISTANCE BETWEEN WELLHEAD AND PRESSURE TANK** for submersible or turbine deep-well pump.
G3	**HORIZONTAL DISTANCE BETWEEN WELLHEAD AND OPEN TANK OR RESERVOIR** for submersible or turbine deep-well pump
H1	**ELEVATION OF PRESSURE TANK** above shallow-well pump or deep-well jet pump.
H2	**ELEVATION OF PRESSURE TANK** above wellhead for submersible or turbine deep-well pump
H3	**ELEVATION OF WATER LEVEL** in open tank or reservoir above wellhead

	FRICTION LOSSES expressed as additional elevation
J1	Pipeline between shallow-well pump or deep-well jet pump and pressure tank
J2	Pipeline between wellhead and pressure tank for submersible or turbine deep-well pump.
J3	Pipeline between wellhead and open tank for submersible or turbine deep-well pump.
L1	**PRESSURE REQUIRED AT PUMP DISCHARGE** of shallow-well pump or deep-well jet pump with pressure tank L1 = H1 + J1 + cutout pressure (all reduced to lb/in² or kPa corresponding to catalogue table)
L2	**HEAD OR PRESSURE REQUIRED AT WELLHEAD** with submersible or turbine deep-well pump with pressure tank L2 = H2 + J2 + cutout pressure (all reduced to lb/in², kPa, feet head of water, or metres head of water corresponding to catalogue table or curve)
L3	**HEAD OR PRESSURE REQUIRED AT WELLHEAD** with submersible or turbine deep-well pump (open discharge) L3 = H3 + J3 (reduced to lb/in², kPa, feet head of water, or metres head of water corresponding to catalogue table or curve)
M1	**TOTAL PRESSURE OR HEAD** developed across shallow-well pump or deep-well jet pump with pressure tank M1 = F1 + L1 (expressed in coherent units)
M2	**TOTAL PRESSURE OR HEAD** developed across submersible or turbine deep-well with pressure tank M2 = F2 + L2 (expressed in coherent units)
M3	**TOTAL PRESSURE OR HEAD** developed across submersible or turbine deep-well pump (open discharge). M3 = F2 + L3 (expressed in coherent units).
W	Shallow-well pump (offset from well). Deep-well jet pump (offset from well).
X	Foot valve (if used) of shallow-well pump. Injector of deep-well jet pump. Submersible deep-well pump. Bowl assembly of turbine deep-well pump — for vertical installation only.
Y	Shallow-well pump (installed at wellhead). Deep-well jet pump (installed at wellhead) Discharge-head assembly of turbine deep-well pump
Z	Shallow-well pump. Deep-well jet pump Pressure tank of submersible deep-well pump installation Discharge-head assembly of turbine deep-well pump — for vertical installation only

FIGURE 2.1-3b
PUMPING SYSTEM HYDRAULIC TERMINOLOGY

The volume in U.S. gallons per hour is based on the pump running the equivalent of five full hours at rated capacity during an average day. It does not run in this fashion, of course, because the sun resource varies throughout the day and for the morning and evening hours the solar input is sufficient to drive the pump only at a fraction of it's rated capacity. Thus the 5 hours per day illustrated would be made up of probably three hours pumping generally at full rated capacity with another seven hours at varying percentages, the total output of which would make up the equivalent of 5 hours of full pumping.

Concept of metres to the fourth (m4)

The power required to operate a pumping system depends mainly on two basic variables; first the volume of water to be delivered at the delivery point and secondly the height through which that pump has to raise the water from it's source to the delivery point.

When both these terms are expressed in SI units, the product of the two i.e. the volume in cubic metres and the total head in metres multiplied together, gives a quantity of metres to the fourth power (m4). This figure can be a useful descriptive term of the relative size of the pumping system. Thus a system of type C in Table 2.1-1 which delivered 20 cubic metres per day through a total head of 20 metres would be described as a system of 400 m4. Type A at 60 cubic metres and 2 metre head would be described as 120 m4 and would require approximately 1/3 the solar array to operate. This term (ie m4) will be used in the this context through this report.

Pump Types

Although there are many pump designs and methods of classifying these, the question of economics and efficiencies limit somewhat the range of pumps that are appropriate for use in solar powered systems and these are discussed in section 2.2. Table 2.1-2 lists the various types of pumps and water lifting devices which can be identified.

Category and Name	Construction	Head range (M)	Power range (W)	Output	Efficiency	Cost	Suction Lift?	Status for Irrigation
I DIRECT LIFT DEVICES								
Reciprocating/cyclic								
Watering can	1	>3	•	•	•	•	x	✓
Scoops and bailers	1	>1	•	••	•	•	x	✓
Swing basket	1	>1	•	••	•	•	x	✓
Pivoting gutters and "dhones"	2	1-1.5	•	••	••	••	x	✓
Counterpoise lift or "Shadoof"	2	1-4	•	••	••	••	x	✓
Rope & bucket and windlass	1	6-60	•	•	•	•	x	✓
Self-emptying bucket or "mohte"	2	3-8	••	•••	•	••	x	✓
Reciprocating bucket hoist	3	100-600	••••	••••	•••	•••••	x	x
Rotary/continuous								
Continuous bucket pump	2	6-60	••	••	•••	••	x	✓
Persian wheel or "tablia"	2	3-10	••	•••	•••	••	x	✓
Improved Persian wheel "sawafia"	2	3.15	•••	••••	••••	•••	x	✓
Scoop wheels or "sakia"	3	>2	••	••••	••••	••••	x	✓
Waterwheels or "noria"	2	>6	•	••	••	••	x	✓
II DISPLACEMENT PUMP								
Reciprocating/cyclic								
Piston/bucket pumps	2 & 3	2-200	•••	•••	•••••	••••	✓	✓
Plunger pumps	3	100-600	•••	•••	•••••	•••••	✓	?
Diaphragm pumps	3	6-10	••	•••	••••	•••	✓	✓
"Petropump"	3	10-100	••	••	•••••	••••	✓	?
Semi-rotary pumps	3	6-10	•	••	••	••	✓	x
Gas or vapour displacement	3	6-60	••••	••••	•••	•••	✓ or x	?
Rotary/continuous								
Gear and lobe pumps	3	10-20	•	•	••	•••	✓	x
Flexible vane pumps	3	10-20	••	•••	•••	••••	✓	x
Progressive cavity (Mono)	3	10-100	•••	•••	••••	••••	x	?
Archimedean screw	3	>2m	••	••••	•••	•••	x	✓
Open screw pumps	3	>6m	••••	•••••	••••	•••••	x	✓
Coil and spiral pumps	2	>6m	••	••	•••	•••	x	✓
Flash-wheels & treadmills	2 & 3	>2m	••	••••	••	••	x	✓
Water-ladders "Dragon spines"	2	>2m	••	•••	•••	•••	x	✓
Chain (or rope) and washer	2 & 3	3-20m	•••	•••	••••	••••	x	✓
Peristaltic pump	3	>3m	•	•	•••	•••	✓	x
Porous rope	3	3-10m	••	••	?	?	x	?
III VELOCITY PUMPS								
Reciprocating/cyclic								
Inertia and "joggle" pumps	2 & 3	2-4	•	••	••••	••	x	✓
Flap valve pump	1 & 2	2-4	•	•	••	•	x	✓
Resonating joggle pump	2	2-10	••	••••	••••	•••	x	?
Rebound inertia	3	2-60	••	•	••••	•••	✓	x
Rotary/continuous								
Propeller (axial flow) pumps	3	0-3	••••	•••••	••••	••••	x	✓
Mixed flow pumps	3	2-10	••••	•••••	••••	••••	x	✓
Centrifugal (volute) pumps	3	3-20+	•••••	•••••	••••	•••	✓	✓
Centrifugal (turbine) pumps	3	3-20+	•••••	•••••	••••	••••	✓	✓
Centrifugal (regenerative) pumps	3	10-30	•••	•••	•••	••••	✓	x
Jet pumps (water, air or steam)	3	2-20	•••	•••	••	•••	x	x
IV BUOYANCY PUMPS								
Air lift	3	5-50	••	•••	••	••••	x	x
V IMPULSE PUMPS								
Hydraulic ram	3	10-100	••	••	•••	•••	? x	✓
VI GRAVITY DEVICES								
Syphons	1, 2 & 3	1-(−10)	—	•••••	—	••	—	✓
Qanats or foggara	2	—	—	••	•••••	—	—	✓

Construction: 1 Basic 2 Traditional 3 Industrial

Very low	•	Medium-high	••••	Yes ✓	Yes ✓
Low-medium	••	High	•••••	No x	Possible ?
Medium	•••				Unlikely x

TABLE 2.1-2

TYPES OF PUMPS AND WATER LIFTING DEVICES

PV Technology

Photovoltaic technology and the physics of solar cells will not be extensively dealt with in any detail here as there are many readily available books that go into complete detail. A very brief description, however, is given here for readers who may have had no contact at all with this technology.

Photovoltaics is the technology of converting sunlight directly into electricity. This is accomplished through the use of solar cells encapsulated in a weather proof module package and subsequently mounted on a structure to be exposed to incident sunlight at an angle optimized for the application.

During exposure to the sunlight, the energy from the sun is converted to electricity by the photovoltaic effect which produces a voltage across a semiconductor device, normally of purified silicon, which is called a solar cell. Electricity produced by the solar cell is direct current with a voltage output relatively constant while the current varies with the intensity of the incident radiation and the exposed area. Commercial energy conversion efficiencies are in the general range of 10%. At noon on a bright summer day 1000 watts of power is incident from the sunlight on an area one metre squared and electrical output of solar cells covering that one square metre of area will be approximately 100 watts. If this input is maintained for one hour then 100 watt hours of energy will have been produced by the system.

The photovoltaic devices commonly in use today for power applications are made of crystaline silicon and their output is essentially linear relative to the solar input. Thus when the solar irradiance is reduced to only one half or 500 watts per metre squared, the output of the above system of one metre squared will have a corresponding output reduction also of one half to 50 watts.

PV devices and arrays are described in terms of peak watts (Wp) which is the power output anticipated under "standard conditions" of 25 degrees C cell temperature and illumination of 1000W/m2.

Another characteristic of the PV device is that it's output in terms of current and voltage will vary from zero to a specific maximum depending on the device and the resistance or impedance of the load to which it is connected. There is, however, one combination of current and voltage value for the system which produces the maximum power output. This "maximum power" comination or point may or may not coincide with the combination resulting from a specific irradiance, motor, and load. Electronic controls are sometimes used to maintain ideal conditions for the PV device to maximize the power output while in other systems a storage battery connected across the device establishes the voltage for operation and this ideally will be near the maximum power voltage.

Tracking & Concentration

Rotating the photovoltaic array on one or two axis to always point at the sun and maximize the solar irradiation throughout the day will increase the output of the system. However due to uncertain mechanical reliability, diffuse light conditions, and other reasons this "tracking" is not extensively used on remote power systems.

Additionally, enhancement of the solar irradiance on the face of the PV array can be achieved with mirrors or reflectors. However these again are not commonly used in remote locations due to uncertain reliability, the need for precise tracking and other difficulties. Consequently this report does not deal with the issues of tracking or concentration for PV systems.

Batteries

Batteries for electrochemical storage as for example in the form of lead acid storage batteries are not generally used with pumping systems. Their characteristics will not be reviewed in any detail here.

Efficiencies

A prime concern in a photovoltaic pumping system is the performance efficiency of both the overall system and it's subcomponents. This concern extends as well to the daily efficiency since the PV system will operate over varying inputs throughout the course of a day as compared to the relatively constant input for most conventionally powered pumping systems. Thus the system efficiency over the period of a day will include not only the instantaneous peak efficiency which of course is important, but also the integrated efficiencies of the system as it operates over the varying input conditions both in the morning and evening shoulder periods as well as the brightest mid-day hours. Intermittent cloud cover, temperature, haze and other atmospheric pollutants will also affect the operating efficiency.

A system with lower efficiencies will require a larger solar array at additional cost in order to provide the additional power to affect the reduced efficiencies. Depending on the overall system cost and performance however, these extra costs may be justified.

Another element in considering the efficiency of pumping units is the sensitivity of the system's efficiency to a change in pumping heads. If for instance, the water level in the well varies by two metres throughout the year, the pump system may maintain it's efficiency at the lower water levels or the efficiency may drop off drastically. This is particularily critical in low head pumping situations where the total head may only be three to five metres and a two metre change is a significant percentage of the original design specification.

System Design Considerations

In the design of a photovoltaic powered water pumping system it is normal to start with the load requirements. For some applications the load definition is relatively simple but in the case of village water pumping systems for instance, a number of judgemental decisions usually are required. These include the assessment of the previous water sources, the stability of the local population, and whether or not livestock watering will be expected. While subsistence level living is possible on five litres of water per day per capita, a common rule of thumb requirement for native villages is forty litres per day per capita. This contrasts incidentally with a published U.S. consumption figure for 1985 of 5,280 litres per capita per day.

Once a load definition has been made it is necessary to consider the availability of water throughout the requirement period which will be twelve months for a village water supply, but perhaps seasonal for irrigation purposed. A decision must be made where, whether and how much storage of the pumped water will be required.

Coincident with the need for the water resource throughout the year is the need for the solar resource to provide the power for the pump. While many tropical areas will have a relatively constant daily average sunshine throughout the year, other locations will suffer from rainy seasons which will affect the size of the array and the required storage depending upon the application.

The instability of the solar input as a result of changing cloud conditions may affect also the decision as to the type of pump that would be used for the application. Figure 2.1-4 illustrates the typical daily variations possible in solar irradiation.

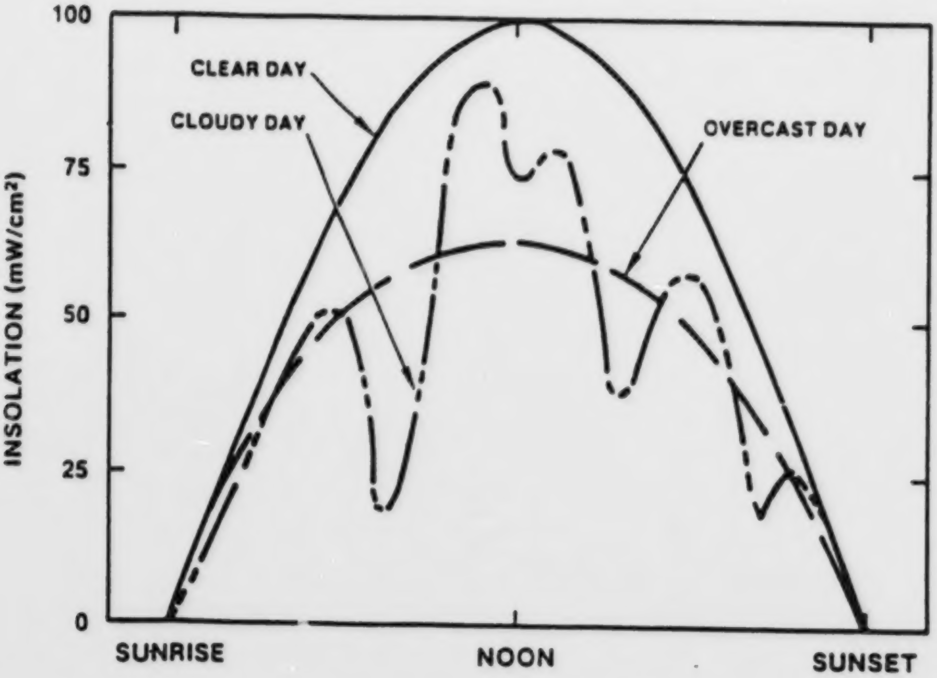


FIGURE 2.1-4
TYPICAL VARIATIONS IN SOLAR IRRADIATION

In consideration of the variations during the year of both the water level and the sunlight available, a "design month" will be selected which will reflect the highest head for the water to be pumped with the worst solar irradiation. These "design month" figures will normally be used in a simple manual calculation of the system requirements.

The friction losses incurred through the hydraulic piping and bends can be calculated using the conventional hydraulic engineering rules. These are added to the static head to give the overall total head through which the water must be pumped. For photovoltaic powered pumping systems the pipe diameters are generally over-sized to minimize these friction losses. Using the pump/motor system average energy efficiency or the pump and motor individual efficiencies as tested, rated, or estimated, the power input to the motor can be calculated.

The impact of the control element must be assessed to then relate the input requirements of the motor to the output capabilities of the array. From these calculations the size of the photovoltaic solar array will be determined.

The above procedure may be used to size a system to deliver a specific quantity of water at a specific site.

Alternatively the characteristics of a given motor pump array package may be known and the procedure is then to determine the amount of water that this given package can produce at a given site. A form used for calculation of system sizing is given in Figure 2.1-5 for manual calculations.

Nomograph Sizing

Nomographs have also been developed (Figure 2.1-6 and Figure 2.1-7) to assist the manual design process and reduce or eliminate detailed calculations. These nomographs can be used to determine the size of the PV array required to meet the hydraulic load during the critical design period. In addition they generate the information needed to select motor and pump size. The nomographs replace a number of basic steps in the system sizing and are used as follows:

SOLAR PUMP SYSTEM SIZING

Location .... Latitude .... Longitude ....

Design Month

Design Month hydraulic energy requirement .... MJ

Design Month head .... metres

Design Month global irradiation on array .... MJ/m^2

Average sub system energy efficiency .... %

Peak sub system power efficiency .... %

Step	Calculations
1. PV array size	Required electrical energy .... MJ PV array size ....Wp
2. Motor size	Rated motor input power .... Watts
3. Pump size	Rated peak hydraulic power .... Watts Rated flow rate .... lit/sec at .... metres head
4. Pipe Diameter	Diameter .... (mm) for head loss of .... (m) at rated peak flow rate

FIGURE 2.1-5
FORMAT SHEET FOR CALCULATION OF SYSTEM SIZE

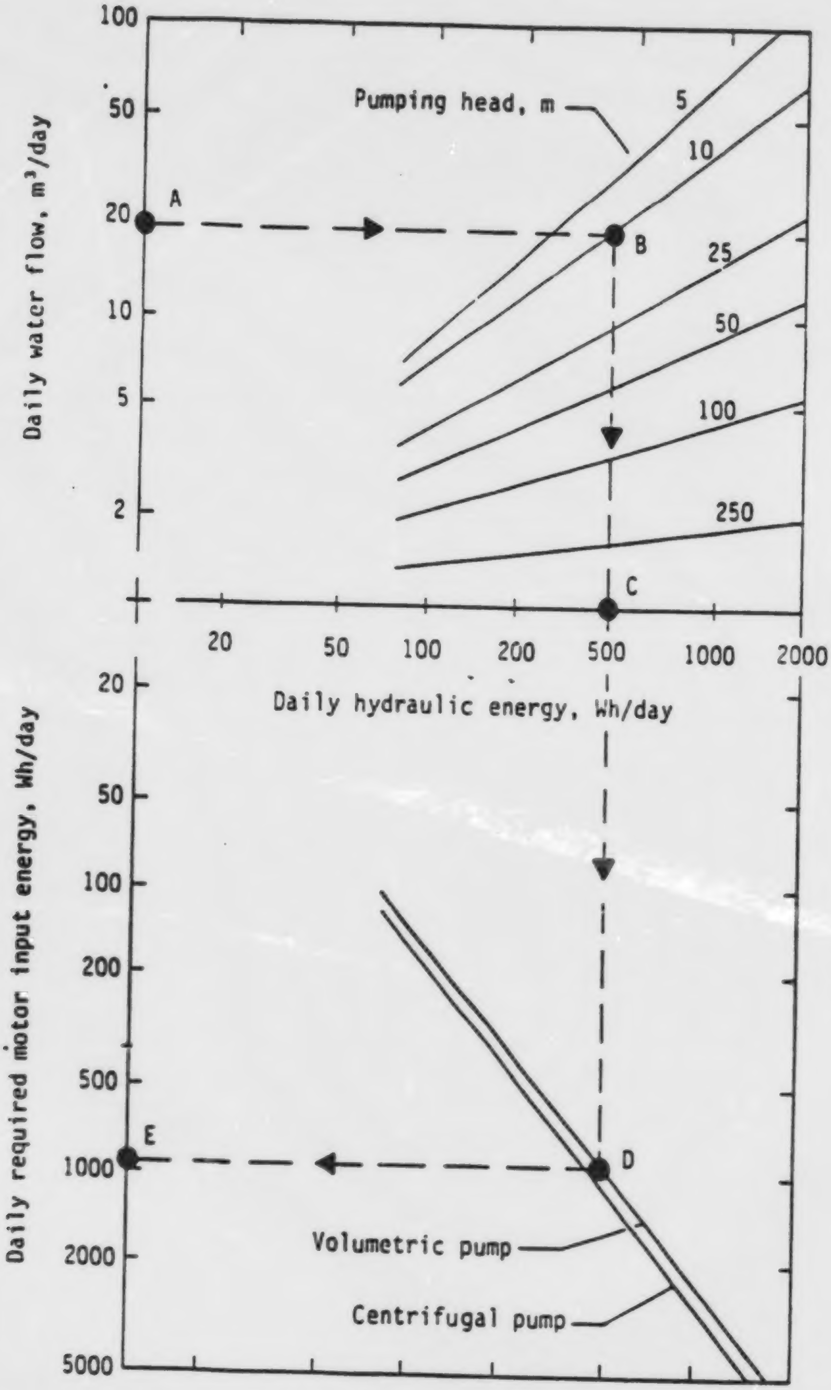


FIGURE 2.1-6

HYDRAULIC ENERGY NOMOGRAPH

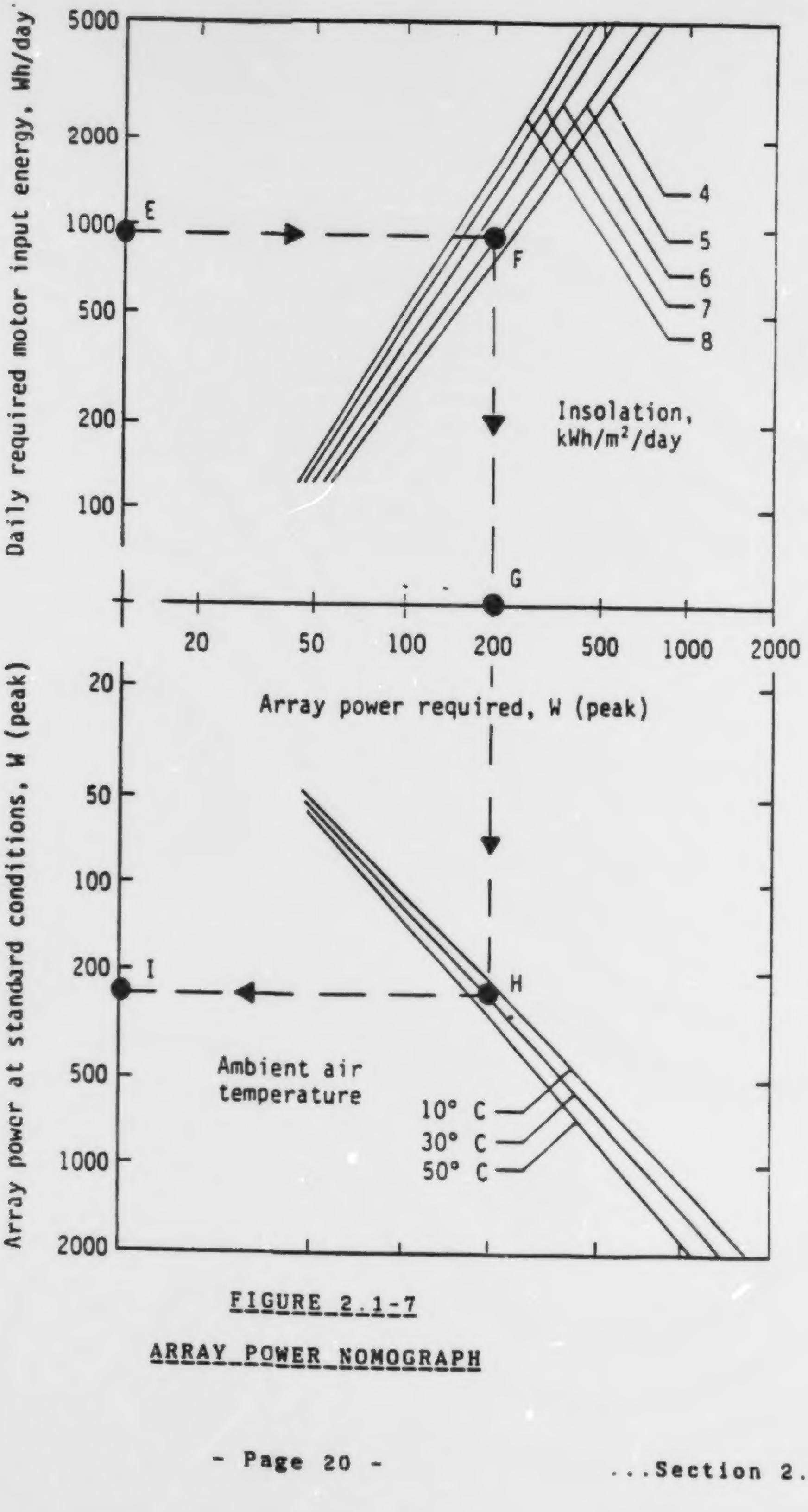


FIGURE 2.1-7

ARRAY POWER NOMOGRAPH

The starting point is point A on the Hydraulic Energy Nomograph. This water requirement must be specified by the user. Moving next to point B, the pumping head (the pumping head at the well site) leads to point C (the hydraulic power). Point D (reflecting an estimate of volumetric pump system efficiency versus that of a centrifugal pump) leads to point E (which gives the daily required motor energy). Now move to the Array Power Nomograph.

Starting at point E (daily required motor energy, as determined on the previous nomograph), move to point F (the insolation level). The value for insolation level can be obtained from various solar design sources. Point F leads to point G (the array power requirement). The motor rating should exceed the array power by 25% to protect against motor over loading. Lastly, point H (the ambient air temperature obtained from local weather data) leads to the required rated array power, in Watts peak (Wp), point I.

A suggested format sheet for specifying solar pump performance, and which summarizes the details of a PV powered water pumping system, is given in Figure 2.1-8.

SOLAR PUMP PERFORMANCE SPECIFICATION

Location .... Latitude .... Longitude ....

1. Water source mean static lift .... m

2. Delivery system
   Type ....
   Length .... m
   Pipe diameter .... mm
   Efficiency .... %

3. Storage system (when applicable)
   Volume .... m^3
   Height .... m

4. Design month details
   End use water requirement .... m^3/day
   Pumped water requirement .... m^3/day
   Hydraulic energy requirement .... MJ/day
   Solar irradiation on PV array .... MJ/m^2/day

5. Solar pump performance and water requirement

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solar Irradiation (MJ/m^2/day) on PV array												
Pumped water requirement (m^3 per day)												
Pumped water (m^3 output/day)												

6. Solar pump specification
   PV array size .... Wp
   PV array tilt ....
   Sub-system energy efficiency .... %
   Sub-system peak power efficiency ..... %
   Motor Rated Power .... W
   Pump rating .... lit/sec at .... m head

FIGURE 2.1-8

FORMAT SHEET FOR SPECIFICATIONS OF SOLAR PUMP PERFORMANCE

2.2 - TRADITIONAL PV PUMP TYPES

Any pump can theoretically be powered by a photovoltaic power source. In practice there have been a number of pump configurations that have evolved that have proven most appropriate for use with PV arrays for various applications. The depth of the water below the delivery point has a large bearing on which type of pump is appropriate for that application. In general, applications are considered to be shallow when under 8 metres as opposed to deep well applications when the head is over 8 metres.

The principal configurations of solar pumps are illustrated in Figure 2.2-1 which illustrates the :

Type A - submerged pump and motor

Type B - submerged pump, surface mounted motor, rotary drive shaft

Type C - submerged pump cylinder surface motor recipicating drive shaft

Type D - floating motor and pump

Type E - surface mounted pump and motor - suction feed from water

A table of approximate 1988 prices for the typical size range of solar configurations listed in Figure 2.2-1 are given in Table 4.0-1 in section 4.0.

Pumps used in PV applications are generally described as being centrifugal type or positive displacement type. This describes the physical means of moving the water and these are illustrated in Figures 2.2-2 and 2.2-3.

In describing these types of pump sets the following abbreviations are commonly used:

SMC - submersible multi stage centrifugal
SPSM - submersible pump surface motor
FP + M - floating pump and motor
SMSP - surface mounted suction pump (8 metres maximum)
RPDP - recipricating positive displacement pump
RPCDP - rotary progressive cavity displacement pump

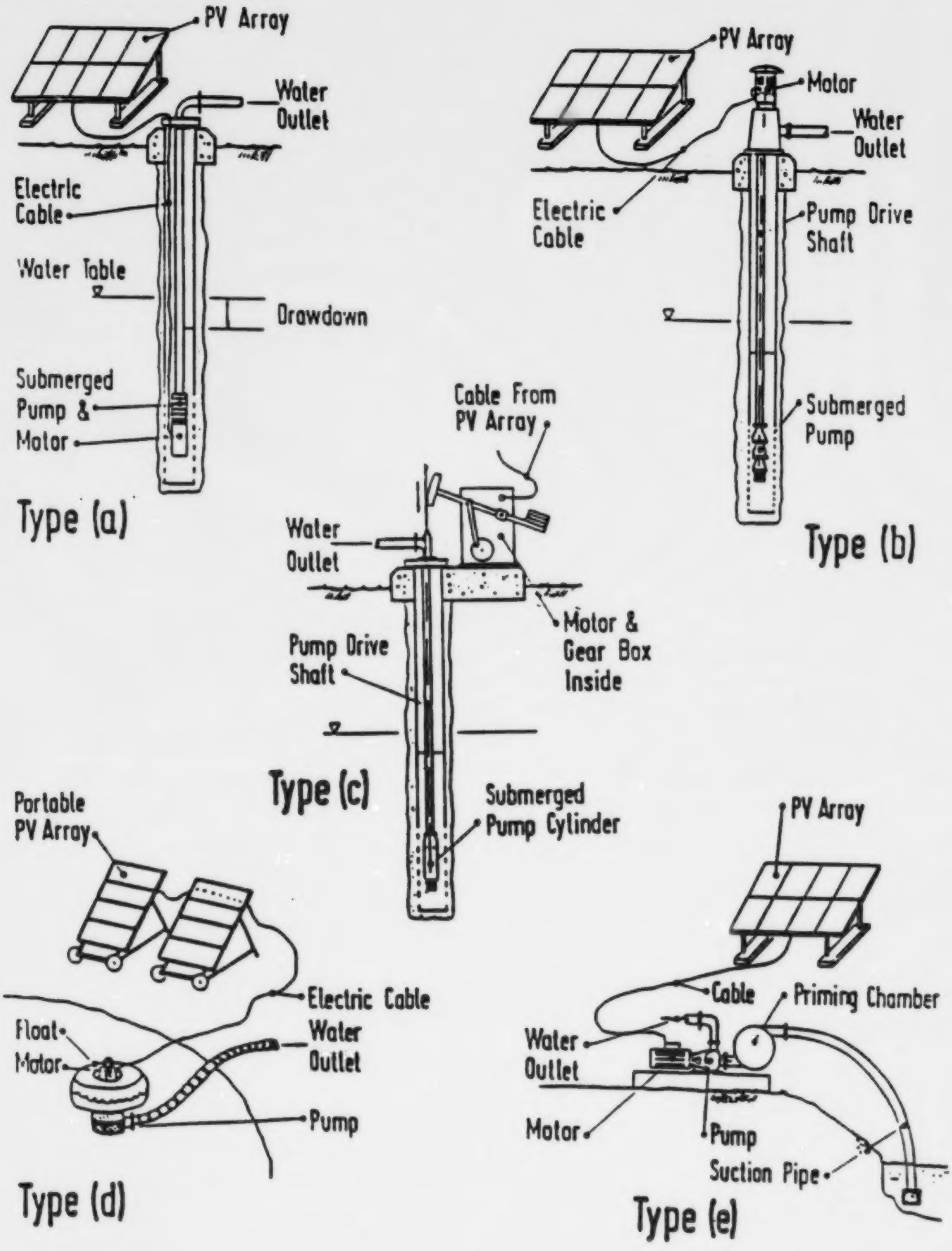
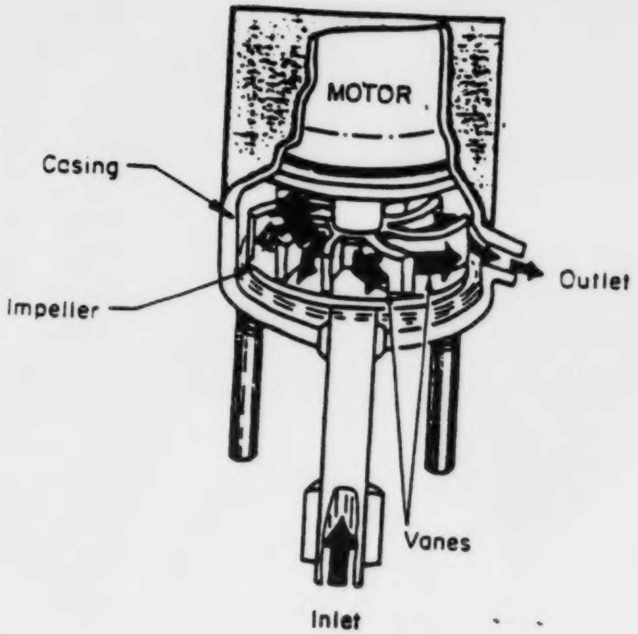

PV Array
Water Outlet
Electric Cable
Water Table
Drawdown
Submerged Pump &
Motor
Type (a)
PV Array
Motor
Water Outlet
Electric Cable
Pump Drive Shaft
Submerged Pump
Type (b)
Cable From PV Array
Water Outlet
Motor & Gear Box Inside
Pump Drive Shaft
Submerged Pump Cylinder
Type (c)
Portable PV Array
Electric Cable
Float
Motor
Water Outlet
Pump
Type (d)
PV Array
Cable
Priming Chamber
Water Outlet
Motor
Pump
Suction Pipe
Type (e)

FIGURE 2.2-1

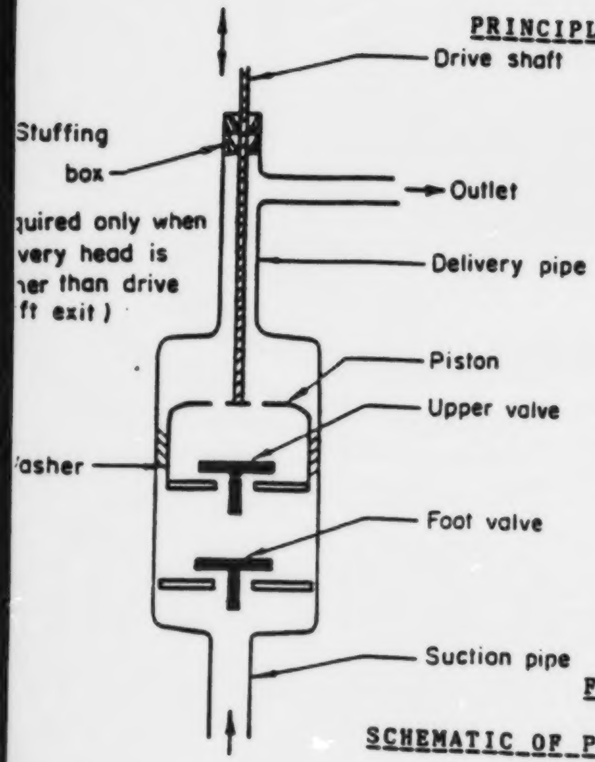
PRINCIPAL CONFIGURATIONS OF SOLAR PUMPS


MOTOR
Casing
Impeller
Outlet
Vanes
Inlet

Principle of a centrifugal pump. Water is thrown out from the centre of the pump because of the centrifugal force created as the impeller rotates.

FIGURE 2.2-2

PRINCIPLE OF CENTRIFUGAL PUMP


Drive shaft
Stuffing
box
quired only when
very head is
ner than drive
ft exit)
Outlet
Delivery pipe
Piston
Upper valve
asher
Foot valve
Suction pipe

Schematic of a positive displacement pump. When the piston moves down, the foot valve closes and water passes to the chamber above the piston. On the upward stroke the upper valve closes, the foot valve opens and water is lifted to fill the chamber below the piston

FIGURE 2.2-3

SCHEMATIC OF POSITIVE DISPLACEMENT PUMP

It should be noted that the reciprocating positive displacement pump as illustrated Type C in the Figure 2.2-1 is also known as a "jack pump" and is of a type quite commonly used in the petroleum industry and is most appropriate for deep wells (i.e. from 65m to 500 m).

Each of the above configurations are appropriate for certain ranges of volumes and heads for most efficient operation. A summary of these applications is shown graphically in Figure 2.2-4 on the following page. The size of the array for the application is also indicated on the curves shown as the number of peak watts. The diagonals shown are the ranges of the pump systems output in terms of metres to the fourth (m4) as previously described. It is seen that on this log-log plot that the relationship is essentially linear and provides a convenient and reasonable basis for system comparison.

In addition to the major types discussed above other types have been used including:

- diaphram pumps
- axial flow (propeller) pumps
- deep turbine pumps

Electrical Drives

Traditional PV pump types can be broken into two main electrical categories, that of direct current (DC) power or alternating current (AC) power. Sub sets of both are created by considering the voltage levels at which the pump motors are designed to operate. While the DC types will be found operating as low as 12 volts for small systems and up to 180 volts for larger systems the AC motors are generally designed to operate at conventional 110, 220 or 240 volts. Larger applications will use higher voltages and multiple phases to run the motors with appropriate inverters being used to create the alternating current.

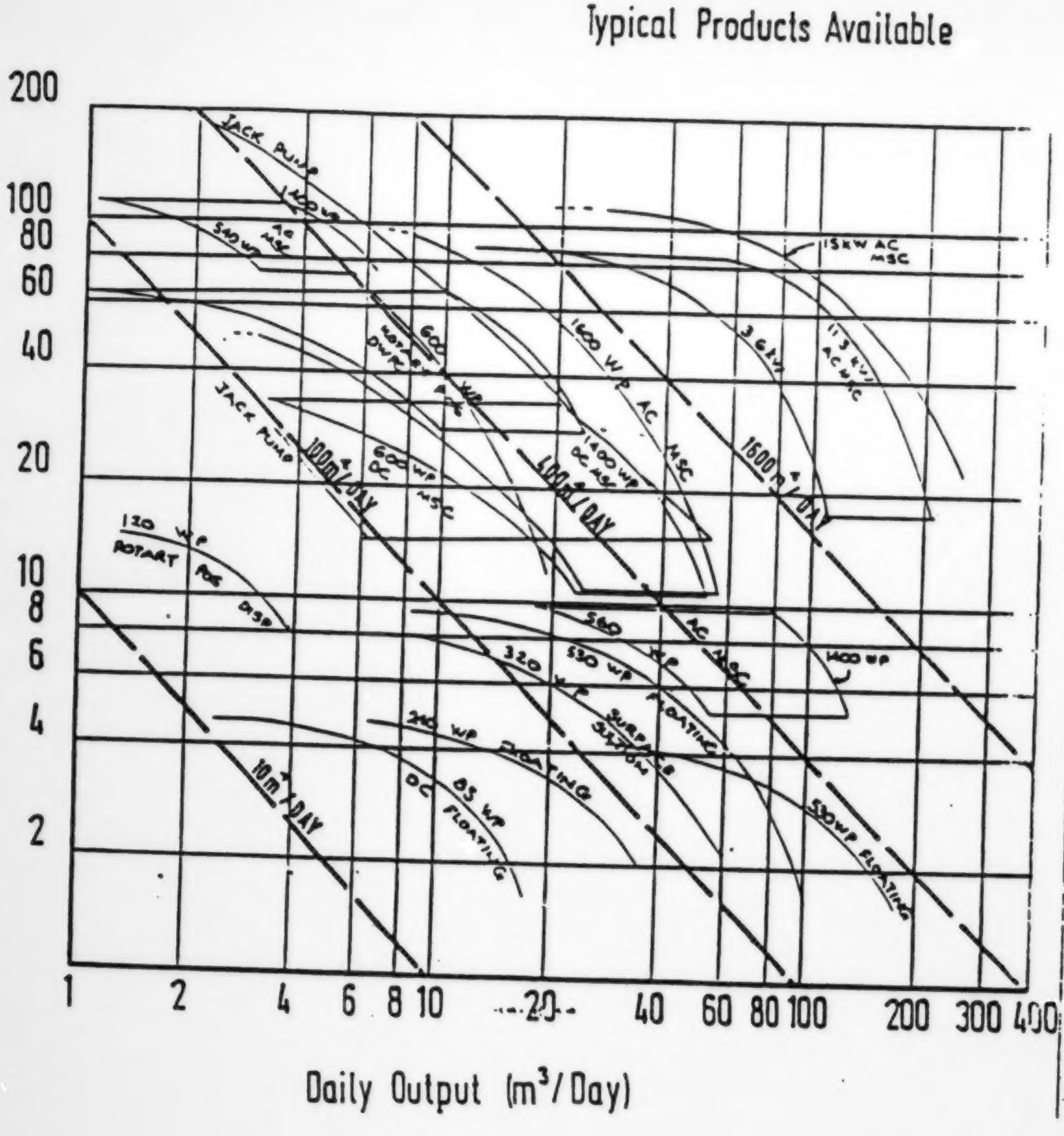


FIGURE 2.2-4

APPROPRIATE RANGES FOR COMMERCIAL PV PUMPS

DC Motors

The use of DC powered motors is attractive as this is the form of power delivered by the photovoltaic array. A system can be configured very simply with the DC motor being connected directly to the array without any interfacing controls of any type. In practice, an interface and control strategy is usually utilized called a "maximum power tracker" (MPT) which is designed to allow the solar array to operate at it's appropriate voltage to obtain the maximum power while delivering to the motor a different voltage and current which will allow the motor to utilize the total power developed by the array.

The maximum power tracker thus performs also the function of a DC converter and often will be designed to deliver to the DC motor for more efficient operation a voltage higher than the array output.

While DC motors are slightly more efficient than AC motors in general, they are also generally more expensive. One of the main drawbacks to utilizing a DC motor is the need to maintain the brushes which enable the transfer of electricity to the rotating shaft windings. Improvements have been made in the life expectancy of brushes for DC motors, however their replacement is normally required (at the outside) between five and ten thousand hours of operation.

A problem resulting from replacing the brushes on sealed submersible DC motors has apparently been the difficulty of maintaining an adequate seal to keep out the water after the brushes have been replaced. Even for surface mounted units that do not encounter the sealing problem, the simple fact of maintaining spares in a third world environment and relying on effective routine maintenance for continued operation is seen as a low probability in the eyes of experienced workers in the area. Thus more potential problems are perceived by users with brushed DC motors, particularly on submerged units than with AC motors.

Brushed DC motors can utilize either a "wound" field for the stator or a permanent magnet which eliminates certain electrical losses in the field winding and is a more commonly seen unit today. The permanent magnet (PM) motor is slightly more efficient than the field wound style.

Another popular approach to the DC motors to avoid the problem of brush maintenance, is the "brushless" type DC motor now available in many sizes. The brushless motor does eliminate the maintenance of brushes however it introduces an electronic switching mechanism which has been seen as another potential failure point.

DC brushless motors are electronically commutated and are a very attractive concept for PV pumping. Early versions were complex and not sufficiently reliable. There is a need for a good submersible brushless DC motor pump set and at least one motor manufacturer (Franklin) currently is conducting field trials on improved designs.

AC Motors

Alternating current (AC) power is the normal type of power supplied by the utility grid. Because of this; most motors manufactured today are designed to utilize alternating current for residential, commercial and industrial applications. Due to their simpler construction and the high volume of production of these units they tend to be cheaper in price than DC motors for comparible sizes. For automobile applications this does not hold, but in general the AC motor is more economical.

The difficulty with utilizing AC motors for solar pumping purposes is the variability of the power from the solar source. This variation occurs during the normal course of the rising and setting of the sun and also due to the passage of clouds throughout the day. To utilize an (AC) motor, it is necessary to convert the direct current (DC) power from the solar source into alternating current. This is conventionally achieved by the use of an inverter. Conventional inverters however are not designed to accept varying voltage inputs and are unable to provide a stable power source for the AC motor.

In practice this problem is resolved by utilizing one of two approaches. The one is to design and utilize a special inverter that will accept varying amounts of power from the DC solar source and feed that power to the motor in a variable frequency, variable voltage format which the AC motor can accept. The AC motor can then operate successfully with varying power outputs.

The other alternative is to introduce a storage battery into the system which can provide to a regular inverter a stable voltage input and also a buffer of power from the energy storage that will make up for the varying input from the solar resource. As batteries have an efficiency factor for energy of approximately .75 - .8, there is an energy loss in the system of roughly 20% when the power is stored in and recovered from the battery component.

The current trend is to use the former method of using a special inverter that is designed for pump applications and which will provide a variable frequency, variable voltage output for the pump operation. The most popular motor/pump set currently utilizes this approach and is manufactured by the international pump firm, Grundfos Pumps.

2.3 - INNOVATIVE PUMP TYPES

In addition to the traditional pump types discussed in the previous section there have appeared three pumps in particular that utilize a different configuration which could be classed as innovative. Two are presently on the market while the third is still under development. Detailed testing or independently monitored performance results have not been available for these units. It is not yet possible to make a firm assessment as to their efficiencies or long term reliability. They are mentioned here as an indication of the type of development that is being undertaken in the pumping field and that may be of interest to the PV community.

Ergo Pump

The Ergo pump is a solar power source pump that is designed to fit in a six inch bore hole or open type well. The motor is a direct current brushless motor which is controlled by a micro processor based electronic control built into the upper part of the submerged unit.

This promising unit was designed in Canada and is being marketed through Ergo Industries Corporation of California as well as the Canadian office in Vancouver.

While most submersible pumps are centrifugal type units the Ergo unit is a positive displacement type using reciprocating piston and appropriate transmission. An interesting feature of the pump is the ability to adjust not only the stroke of the piston via cams but also the bore of the piston by utilizing inserts in the piston sleeve assembly to provide the pump with a wider range of applicability.

The pump was exhibited at the 1986 Expo '86 in Vancouver and has had limited marketing since that time. While extensive tests have been made of the unit's performance by the manufacturer in the laboratory and some field testing has occurred in the Vancouver area, no long term documented performance records are available at this time. It is understood that a number of units are presently either in the process of testing or will be shortly and is expected that independent performance data will be available in the near future.

The motor is classed as a high efficiency DC brushless unit which is equipped with rare earth permanent magnets and utilizes sealed for life low friction bearings to avoid the necessity of maintenance. The motor has been custom designed for photovoltaic pumping.

The pump is designed to be powered with approximately 300 watts of PV array with a power input at a voltage level between 50 and 200 volts. The maximum efficiency is reported to be obtained with a current of approximately 2.5 amps and a voltage of 120 volts. The performance table quoted by the manufacturer is shown in Table 2.3-1 and an illustration of the submersible pump is shown in Figure 2.3-1 .

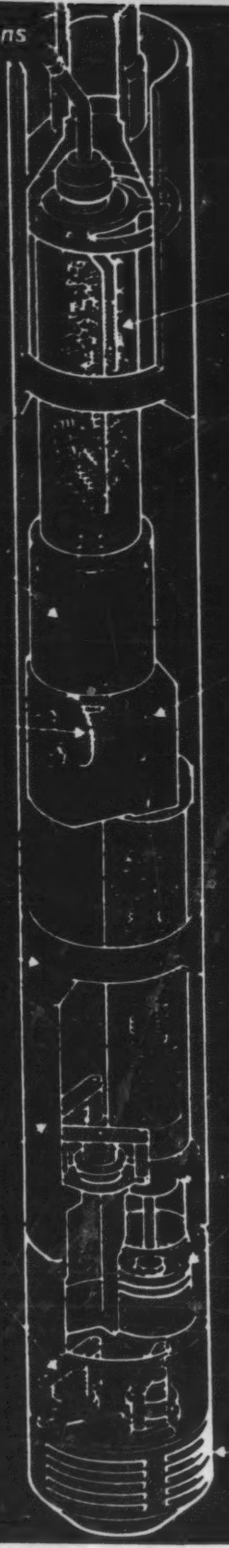
Ergo report that they are presently reworking the design to enable a smaller diameter unit to be produced which will be practical for application in a 4" bore hole well.

Total Head		Output/Minute		Output/Day	
ft	m	US gallons	litres	US gallons	cubic m
6.6	2.0	42	158	20,160	76
16.4	5.0	40	151	19,180	72
23.0	7.0	32	128	15,500	61
33.0	10.0	23	86	10,900	41
41.0	12.5	19	73	9,200	35
50.0	15.0	16	59	7,500	28
66.0	20.0	12	45	5,800	21
83.0	25.0	9	34	4,300	16
100.0	30.0	8	29	3,700	14
116.0	35.0	7	25	3,200	12
132.0	40.0	5	20	2,150	9

TABLE 2.3-1

ERGO PUMP PERFORMANCE

GO High Efficiency Submersible Pump
red specifically for Solar Powered Applications



Reliable microprocessor-based electronic controller drives the motor and determines the overall operating efficiency of the unit. It provides protection in case of malfunction, and detects clogged filters or discharge piping. Provides the longest possible operating day.

Direct current brushless motor with practically no wearing parts. The most reliable motor in the industry.

Adjustable crank, easily accessed in the field to increase the volume of water lifted on each stroke or reduce the torque required in deep well applications. Allows the pump to service a wide range of depths.

Gearbox with [illegible]

[illegible]

Changeable piston-sleeve assembly doubles the range of the pump.

Two sets of corrosion free, high performance intake and discharge valves.

Weight: 38 lbs. 17.2 kg
Length: 49 ins. 1244 mm
Diameter: 5-5/8 ins. 143 mm

Easily removed filter housing for filter service.

FIGURE 2.3-1

ERGO SUBMERSIBLE PUMP

Pulsa: Solar Water Oscillation Pump

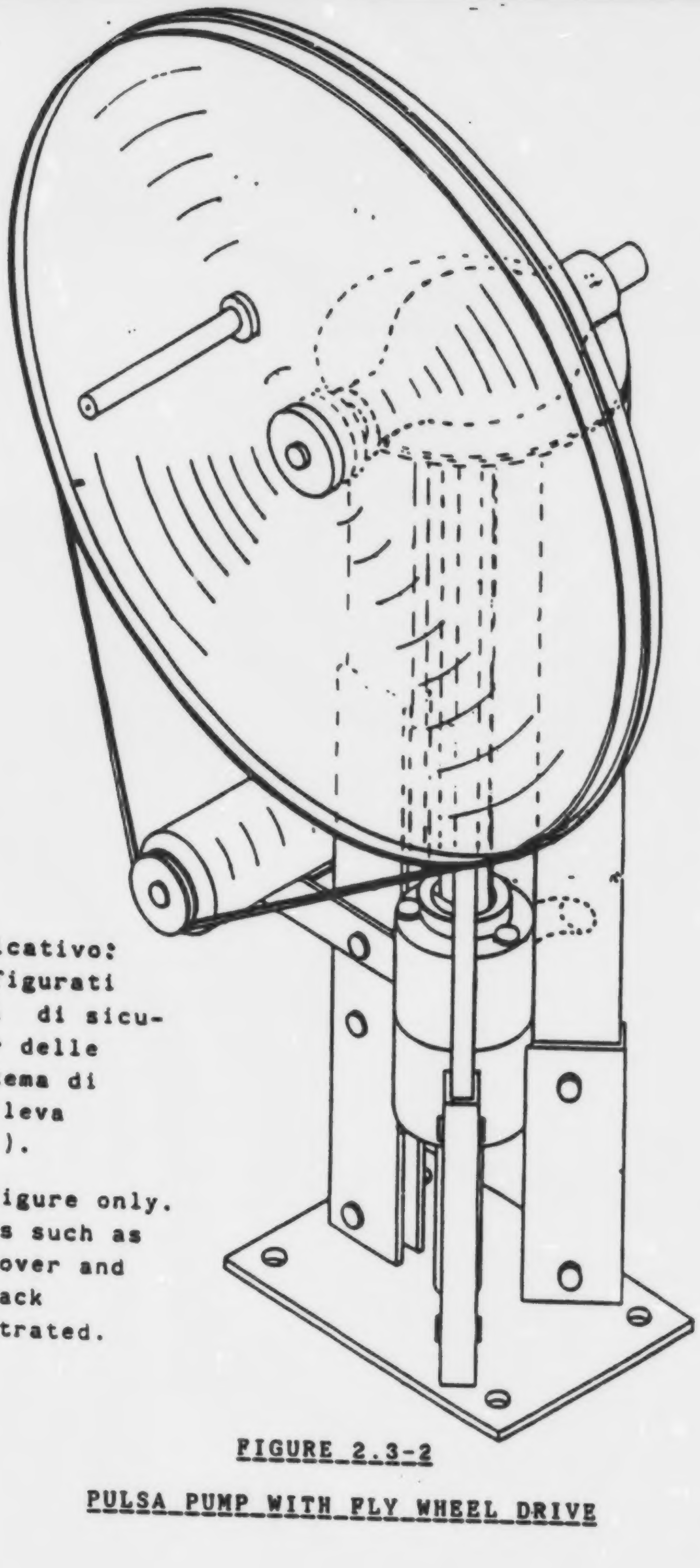
Another innovative pump design which was demonstrated at the 8th European Community Photovoltaic Solar Energy Conference in Florence 1988 is the Pulsa solar pump developed and sold by Fluxinos from Italy. This is a mechanized version of a hand pump that was developed for use in the third world and has been sold for several years as a hand pump.

The Pulsa pump has a unique concept of producing pressure from within the pump to deliver water. It operates basically in the following fashion:

Within a chamber in the submerged portion of the pump are located a number of compressible spheres that are the approximate size of tennis balls. These compress when the hydraulic pressure is increased from above the ground by a positive displacement piston. Due to the pressure the elastic spheres compress accommodating the stroke of the piston. When the hydraulic pressure is released the balls expand and in expanding, force water up the delivery pipe in a pulsating fashion. In the hand operated pump version the hydraulic pressure is applied by a hand lever while in the photovoltaic powered version it is provided by a motor driven lever via a large fly wheel connected to the motor. See Figure 2.3-2.

To accommodate the various heads and volumes of pumping requirements, the number of compressible balls in the lower chamber is adjusted to optimize performance. There appears to be a limiting factor in the speed of operation as oscillations develop after a certain point and no increase in the flow is achieved despite a more rapid operation.

This PV pump was being demonstrated for the first time at the Florence conference and was directly coupled to a PV array without employing a maximum power tracker, battery, or other interface.



N.B. Disegno esplicativo: non sono raffigurati i dispositivi di sicurezza (carter delle cinghie, sistema di scatto della leva manuale, etc.).

Explanatory figure only. Safety devices such as belt system cover and handle fold-back are not illustrated.

FIGURE 2.3-2

PULSA PUMP WITH FLY WHEEL DRIVE

The Pulsa pump was designed and configured specifically for PV pumping in the third world and is being marketed for such applications. The major components of the unit are of stainless steel and appear to be rugged and simple in design. The developers are willing to consider joint ventures for production of the pump offshore with the only required component to be supplied by them being the compressible spheres.

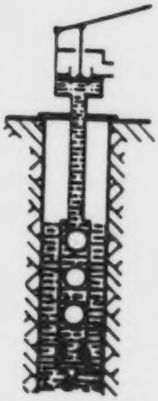
The pumping cycle is illustrated in the Figure 2.3-3.

By eliminating any moving parts below the ground the pump represents an attractive simplicity in it's operation. There is maintenance required, however, for the seals which are anticipated to last 12 to 15 months. For the PV configured unit the DC motor offered with the pump set is a brushed motor which will require brush maintenance in the normal manner. The stated starting threshold for the PV configured unit is approximately 600 watts which is relatively high. It would seem that some development work could lower this considerably; particularily with the introduction of a maximum power tracker unit.

At this time no independent testing results are available nor are any long term monitored performance results. While the design minimizes movement below the ground and allows the motor to be mounted above the ground in a simple fashion, the requirement for seal maintenance lowers the attractiveness of the concept.

Submerged Progressive Cavity

Another innovative pump presently being developed is a modification of the rotary progressive cavity positive displacement pump that eliminates many of the problems associated with having an extended shaft going down the well from the surface mounted pump. This development is being undertaken by Peter Ward and Associates (24) British Columbia who are integrating a DC sealed motor with the drive portion of the progressive cavity pump so that the entire pump motor set is submerged as with the submerged multistage centrifugal (SMC) pumps. The water delivery to the surface would be as in the SMC units and thus eliminating the long drive shaft and the complexities of the conventional rotary progressive cavity pump installation.

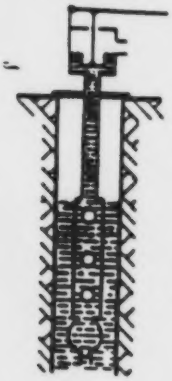


1 DEMARRAGE

Le piston est au contact de la garniture d etancheite.
L'eau est immobile dans le tuyau de refoulement
Les boules sont au repos.
Le clapet d aspiration est fermé.

1. START OF CYCLE

Piston against seal.
Water in pipe still.
Elements at rest.
Foot valve closed.

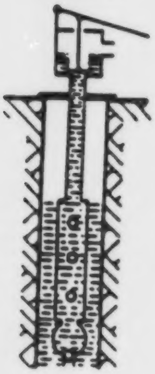


2 DESCENTE DU PISTON

L etancheite est assuree par la garniture.
L eau descend dans le tuyau et va comprimer les boules.
Le clapet d aspiration est ferme

2 PISTON DESCENT

Seal blocks water at top
Water pushed down Elements compressed progressively
Foot valve closed

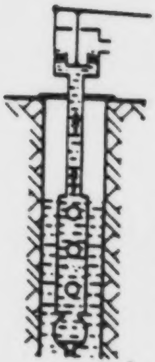


3 POINT MORT INFERIEUR

Point de compression maximum des boules.
L eau est immobile dans le tuyau.
Le clapet d'aspiration est ferme.

3 LOWER DEAD POINT

Elements at maximum compression
Water in pipe still.
Foot valve closed.

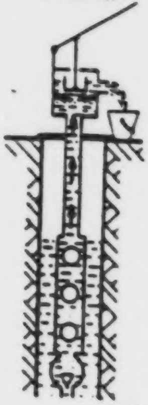


4 RETOUR DU PISTON

Le piston remonte la pression diminue. les boules se dilatent et restituent l energie accumulee lors de la compression à la colonne d eau qui remonte Le clapet d aspiration est toujours ferme.

4 PISTON RETURN

Piston returns Pressure gets lower Elements expand Energy passes to water. Foot valve still closed.

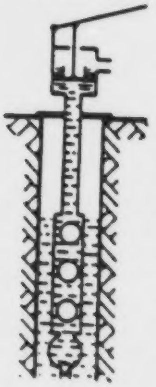


5 POINT MORT SUPERIEUR

C est la phase active de pompage Le piston sort de la garniture et l eau s ecoule librement continuant sa course ascendante Les boules se dilatent jusqu au volume de repos Le clapet d aspiration est ouvert par la depression au bas de la colonne d eau

5 UPPER DEAD POINT

Piston released from seal Water continues upward course Elements take original volume. Foot valve open due to vacuum in pipe



6. FIN DU CYCLE

Le piston redescend et au contact de la garniture d'etancheite, ferme le circuit de compression.

6 END OF CYCLE

Piston returns to rest position in contact with seal.

1. DEMARRAGE
(pour un nouveau cycle)

1. START OF CYCLE

FIGURE 2.3-3

THE PUMPING CYCLE FOR PULSA PUMPS

A similar direction is being taken by a group in Germany that presented a paper at the Florence Conference on the work that they are doing to develop a similar rotating progressive cavity pump with the pump motor set submerged as with the Ward project. The difference is that their work is based on utilizing an AC submersible motor with a variable frequency controller mounted at the surface. The end result would be the same to eliminate the long drive shaft from the surface and the associated installation complications. (15)

The reason people are developing submersible progressing cavity pump sets is the high efficiency of this type of pump compared to centrifugals over a wide range of operating power.

TPK Plastic Pump

This pump development has been abandoned while in the prototype stage but is mentioned here as a Canadian development of a pump which was tested in the original 1983 Halcrow pump investigation. The system incorporated a positive displacement pump of relatively simple design well suited for local manufacture. It was an adaption of a hand pump design comprising relatively low cost plastic parts. Unfortunately performance was considerably below that specified with sub-system efficiency only around 10-12% for the design static head. Losses arose mainly from flexing of the support structure over the support framework and poor sealing of the pump foot valve.

The Halcrow report (3) concluded "although the system concept is an interesting one because of the potential for local manufacture, considerable development was needed to achieve a cost effective reliable design".

2.4 TESTING

Pump Efficiency

Testing and rating of photovoltaic powered pumps is considerably more complicated than testing of a standard powered pump. This is because in the operation of a PV pump the power input is not constant and hence the operating conditions of the pump and output will vary with the solar resource during the normal day. It is relatively easy to establish the efficiency of a given pump operating under specific continuous conditions, but the introduction of the variable aspects which is the real life operating condition for a PV pump complicates the matter considerably.

In actual field conditions at many sites the water level itself will vary either throughout the day or throughout the year with subsequent changes in the pumping head for PV pump set. One approach to characterize the pump set's ability to handle the varying water heads is to establish one efficiency at the design head and in addition to establish the efficiencies when operating at .75 of the design head and 1.5 of the design head. The draft of the International Electrotechnical Commission - Technical Committee 82 - Photovoltaic Solar Power Generating Systems (IEC/TC82) initial pumping standard calls for the instantaneous delivery volume to be higher than 90% of the predicted delivery at design head, at .75 of the design head, 1.15 and 1.3 of the design head.

The instantaneous efficiency of a pump set can be determined under constant conditions but due to the changing conditions throughout a normal solar day particularily if clouds are involved, the real desire is to obtain a prediction of what the pump set would deliver and it's efficiency over a daily period.

Recognizing this difficulty of fluctuating input, the tests performed by the IT Power/Halcrow Team in 1983 (3) identified three "standard days" which represented solar irradiation totals of 4, 5, and 6 kilowatt hours per metre squared over a day. Each hour was assigned an average irradiance level and the pump set performance was assumed to operate over the hour with this constant input and then integrated over the daylight hours. Thus the performance during the early morning and late afternoon hours when the array would receive a lower irradiance were included in the total assessment along with noon hour periods of full sunlight.

In order to achieve the above integration it is necessary to characterize the pump set efficiency at the various levels of power input generated by the solar resource at each hour. This can be done at an appropriate testing facility such as the one at Global Renewable Energy Sources Limited (GRES) which is the previous Halcrow (7) facility.

This facility has the capability of pumping through an actual static head of about forty metres. Higher heads can be produced by utilizing pressure valves to restrict the flow but with reciprocating pumps misleading results and transient operating conditions can be developed. At this facility most tests are carried out without pressure valves to ensure reliability.

The efficiency of a pump motor set is a combination of the efficiency of the pump and the pump motor individually. The overall efficiency is a product of the two such that if the pump has an efficiency of 60% (.6) and the motor has an efficiency of 80% (.8) then the pump set efficiency will be .6 x .8 = .48. During the Halcrow tests, the motors were characterized separately to determine their efficiencies and then the pump/motor set was tested and an overall efficiency determined. The pump efficiency was then calculated by dividing the overall efficiency by the motor efficiency itself.

"State of the art" efficiencies are given in Table 2.4-1 for the common motor pump set configurations.

Specific Capital Cost

From the work of Halcrow on the World Bank Report (3) the concept of Specific Capital Cost (SCC) was developed in order to reflect the capital costs of the system as well as the efficiency of the system. If only the cost per peak watt of the installed system is considered without the efficiency being factored in, then the benefits of efficiency are not considered. Thus a given system A may have higher installed cost per peak watt than system B but because of higher efficiency will in fact deliver more volume of water per dollar of installed cost than system B with a lower cost based only on peak watts.

Lift	Sub-system type	Typical * subsystem daily energy efficiency		Typical * subsystem peak power efficiency	
		Average	Good	Average	Good
2 metre	Surface Suction or floating units with submerged suction utilising brush or brushless permanent magnet d.c. motors and centrifugal pumps	25%	30%	30%	40%
7 metre	- Floating d.c units with submerged pump - submerged pump with surface mounted motor, brush or brushless permanent magnet d.c. motors single or multi- stage centrifugal pumps	28%	40%	40%	60%
20 metre	- a.c. or d.c. submerged multi-stage centrifugal pump set, or - submerged positive displacement pump with d.c. surface motor	32%	42%	35%	45%

TABLE 2.4-1

STATE OF THE ART FOR MOTOR/PUMP SUBSYSTEMS - EFFICIENCIES

The Specific Capital Cost is defined as:

SCC = C / dgVH where

C = the total capital cost of the system (U.S.dollars)

d = density of the water (kilograms per metre cube)

g = gravitational accelleration (m/s2)

V = total volume of water pumped per standard solar day (m cubed)

H = static head (m)

With this definition of units the SCC has units of dollars per joule per day but can also be expressed as dollars per kilojoule per day ($/kJd). In the phase one of Halcrow's report (1) the standard solar day was based on six kilowatt hours per metre squared (6kWh/m2) global insolation on the horizontal plane while in the phase two report of 1983, this was changed to a five kilowatt hour per metre squared (5kWh/m2) standard solar day as it was felt to be more generally appropriate from field experience.

It should be noted that this concept of Specific Capital Cost (SCC) is a valid comparison unit for comparing different solar pumps (without consideration for maintenance costs) but is not appropriate for comparing photovoltaic pumps with diesel pump sets or wind pumping. For valid comparisons across technologies, it is necessary to consider the life cycle costs and this is discussed in detail in section 4.0.

Standard Solar Days

This describes the form of the standard solar day which was developed for the World Bank solar pumping project by Halcrow and Associates to permit comparisons between the performances of different systems over whole day periods.

In order to represent global solar irradiation on a horizontal plane in a simple mathematical form the following equation is used:

$$I(t) = A+B \cos(15t - 180)$$

where I(t) = global irradiance on the horizontal plain (W/m2) at the time t (hours)

An eleven hour period between sunset and sunrise is assummed, which at 20 degrees latitude is equivalent to January 13th. The constants A and B have been derived for three different values of daily global irradiation (E/ day) of 6,000Wh/m2, 5,000Wh/m2 and 4,000Wh/m2. These constants are shown in Table 2.4-2 together with the average hour by hour irradiance levels which rise to each value of E sub-day.

To allow a comparison to be made with the pump performance with data based on total irradiance on the plane of the array, Table 2.4-3 gives the equivalent surface-irradiance data for an array tilted at the latitude angle (20 degrees) for the World Bank solar days.

Figure 2.4-2 gives a graph illustration of the standard solar days as defined by the irradiance levels in Tables 2.4-2 and 2.4-3.

From the testing of the pumps and developing a daily output for the standard days, the preferred method of presenting PV pump performance characteristics is shown Figure 2.4-1.

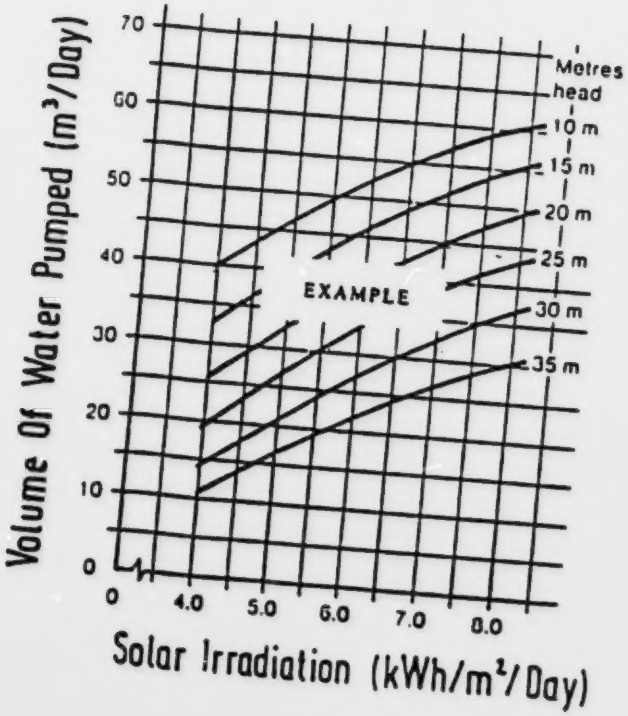


FIGURE 2.4-1

PV PUMP PERFORMANCE CHARACTERISTICS PRESENTATION FORMAT

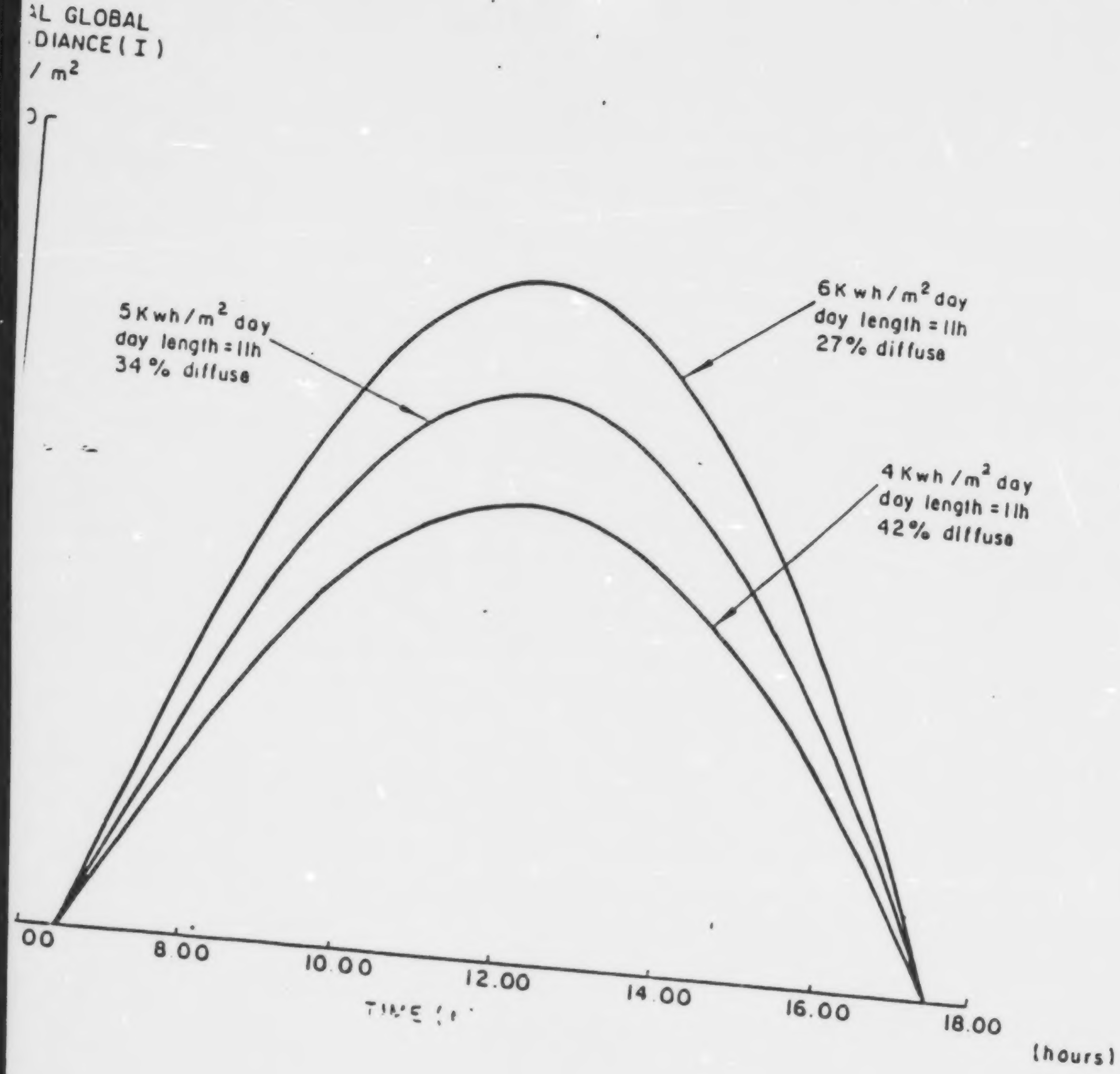


FIGURE 2.4-2

"STANDARD SOLAR DAY"

	E_{day} = 6000 Wh/m^2 t_o = 6.30 h t_f = 17.30 h A = -127.6 B = 977.4	E_{day} = 5000 Wh/m^2 t_o = 6.30 h t_f = 17.30 h A = -106.3 B = 814.5	E_{day} = 4000 Wh/m^2 t_o = 6.30 h t_f = 17.30 h A = -85.0 B = 651.6
HOUR	AVERAGE W/m^2	AVERAGE W/m^2	AVERAGE W/m^2
6.30	0	0	0
6.30 - 7.30	125	105	84
7.30 - 8.30	361	301	241
8.30 - 9.30	564	470	376
9.30 - 10.30	719	599	479
10.30 - 11.30	816	680	544
30 - 12.30	850	708	567
12.30 - 13.30	816	680	544
13.30 - 14.30	719	599	479
14.30 - 15.30	564	470	376
15.30 - 16.30	361	301	241
16.30 - 17.30	125	105	84
17.30	0	0	0

TABLE 2.4-2

HOUR BY HOUR GLOBAL IRRADIANCE FOR FIXED DAY LENGTH OF 11 HOURS

'WORLD BANK' STANDARD SOLAR DAY

Time	Horizontal Irradiance W/m^2	Surface Irradiance W/m^2	Horizontal Irradiance W/m^2	Surface Irradiance W/m^2	Horizontal Irradiance W/m^2	Surface Irradiance W/m^2
	4kWh/m^2		5kWh/m^2		6kWh/m^2	
7	84	145	105	192	125	240
8	241	303	301	391	361	481
9	376	441	470	565	564	691
10	479	546	599	697	719	852
11	544	613	680	781	816	953
12	567	637	708	810	850	988
13	544	613	680	781	816	953
14	479	546	599	697	719	852
15	376	441	470	565	564	691
16	241	303	301	391	361	481
17	84	144	105	192	125	239
Total	4015	4733	5018	6062	6020	7422

TABLE 2.4-3

HOUR BY HOUR IRRADIANCE ON 20' FOR FIXED DAY LENGTH OF 11 HOURS

It has been noted that in addition to the development of the pump performance curves it is also important when doing a technical assessment of a pump to evaluate other factors which would include the following points:

- ease of installation (Installer's Handbook, language special tools)
- ease of maintenance (change of brushes, filter, seals)
- dry running protection
- suitability of materials used (corrosion resistance)
- safety (risk of high voltage shocks)

Experience has shown that an attempted installation by an unskilled crew of a PV solar pump as delivered will highlight weaknesses in the above areas which should be rectified before actual shipments are made to remote locations.

2.5 STANDARDS

Little has been published to-date in the form of standards for photovoltaic power water pumping systems. While some standards exist for turbine pumps and system components, the first international standard dealing with PV water pumping has just reached draft form in the Working Group 3 of the International Electrotechnical Committee 82 on photovoltaic solar energy systems. (IEC TC82/WG3)

This draft document is entitled "Short Term Predicted and Actual Characteristics of Direct Coupled Photovoltaic Pumping Systems" and has the following scope:

"This document defines predicted short term characteristics (instantaneous and for typical daily period) of direct coupled PV water pumping systems. It also defines minimum actual performance value to be obtained on site. It does not address PV pumping systems with batteries.

The parameters defining Photovoltaic power generating systems (PVPGS) and the standard days are described in accordance with the relevant IEC documents to be issued."

At this time "standard days" have not been defined in IEC documents and until these are published the above document will not be valid. Work is proceeding on the development of the associated documents.

Published standards identified in the study todate are:

"Centrifugal, Mixed Flow and Axial Pumps - Code for Acceptance tests - Class C" - ISO 2548-1973 (E)

"International Code for model acceptance tests of hydraulic turbines" IEC publication/93

"International Code for field acceptance tests for storage pumps" IEC publication 198.

"Hydraulic Institute Standards" (for centrifugal, rotary and recipricating pumps) 14th Edition 1983

"Power Test Code, Centrifugal Pumps" PTC 8.2 1965 - ASME

"American Standards for Vertical Turbine Pumps"
ANSI B-58.1 (AWWAE101-61)

"Sump & Sewage Pumps Standards - SSPMA-81 Sump & Sewage Pump Manufacturers"

"Motor operated Water Pumps"
ANSI/UL 778-1983 (U.L. 778)

IEC Technical Committee 115 "Pumps" has two sub-committees and six working groups presently drafting various pumps standards.

3.0 APPLICATIONS

3.0 - General

The bulk of the applications for PV water pumping are currently in the "village water" category. A number of approximately 6,000 PV pumping installations (14) has been estimated to be currently operational throughout the world and these will range from small one or two module installations to the 70 kilowatt installation in Italy at Zambelli. One of the largest irrigation systems is an early U.S. installation at Meade Nebraska for irrigation which comprised a 25 kilowatt PV array.

The distribution of the above PV pumping installation is estimated to be as follows in 1988:

Africa	-	2000
Australasia	-	1300
Latin America/Caribbean	-	600
Canada	-	35
India	-	600
U.S.	-	500
Asia	-	850
Other	-	115
Total	-	6000

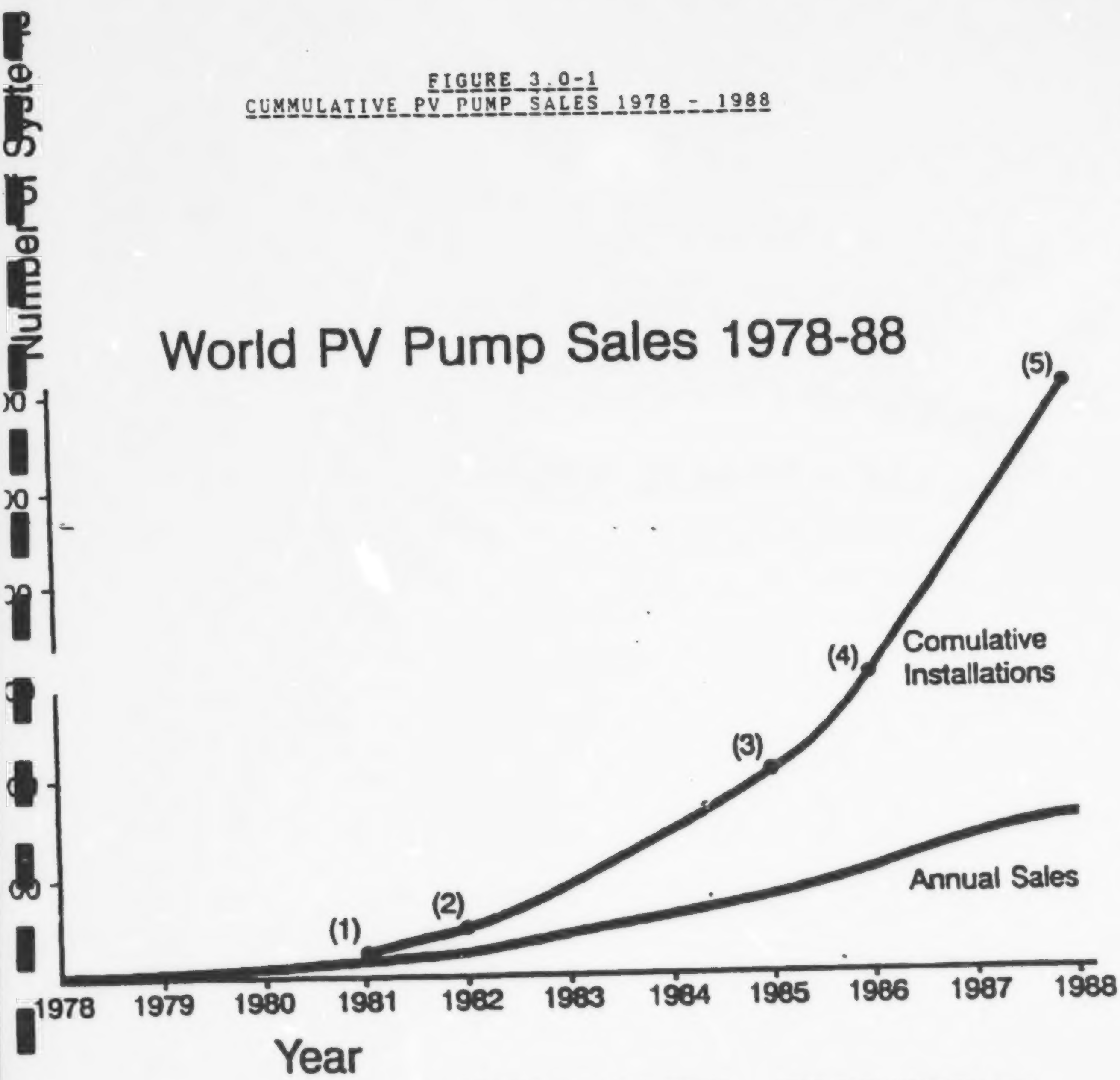
Figure 3.0-1 illustrates the growth of PV pumping installations over the years 1978-1988 as reported by I.T. Power workers.

3.1 - Canadian Installations

Approximately thirty-five PV powered pumps have been identified installed in Canada with the majority being small systems for domestic water supplies at remote residences, either seasonal or year round. Undoubtedly the number is probably in excess of this figure but the smaller systems are very difficult to identify.

Stock watering installations exist in the prairies and a number of experimental or demonstration units have been installed. It cannot be said that PV water pumping is in "wide spread use" at the present time in Canada with these reported numbers.

FIGURE 3.0-1
CUMMULATIVE PV PUMP SALES 1978 - 1988



(1) Derrick et al. Solar World Forum, Brighton, 1981
(2) Derrick et al. 16th IEEE Photovoltaic Specialist Conf. San Diego 1982
(3) McNelis UK-ISES Conf. Newcastle 1985
(4) McNelis 7th EC Photovoltaic Conf. Sevilla1986
(5) Derrick et al. Field Workers Guide to PV Products 1988

The identified installations are as follows:

Location	Size	Application	Record Number
South Alberta	344.Wp	stock watering	32201
Lethbridge, Alberta	215.Wp	stock watering	32202
North Bay,Ontario	430.Wp	cottage pump	32203
Cache Creek, B.C.	470.Wp	stock watering proj.210	32204
Swift Current	387.Wp	stock watering	32205
Montrose,Sask.	258.Wp	cattle watering	32206
Lion's Head	326.Wp	stock watering	32207
South Alberta	212.Wp	stock watering-winter	32208
South Alberta	212.Wp	stock watering winter	32209
Nemiah Valley B.C.	282.Wp	water pumping	32210
Nemiah Valley B C	282.Wp		32211
Prairies	700.Wp	stock Watering	32212
Rondeau Park, Ont	280.Wp	washroom water	32213
Vancouver B C	350.Wp	demo	32214
B C	6 @ 12v	Residential water	32215
B C	6 @ 110v	Residential Water	32216
Lethbridge Alberta	270.Wp	pumping demo	32217
Lethbridge Alberta	172.Wp	pumping demo	32218
Olds Alberta	220.Wp	water pump test	32219
Lethbridge Alberta	258.Wp	pumping demo	32220
Per ld Alberta	212.Wp	water pumping	32221
Red Deer Alberta	212.Wp	pumping demo/test	32222
Bowden	212.Wp	stock watering	32223

TABLE 3.1-1

CANADIAN PV PUMPING INSTALLATIONS

See detailed project reports in Appendix D.

3.2 - International Applications

A detailed list of the numerous PV water pumping projects identified would be impractical here as they are too numerous and similar. Listed in Table 3.2-1 are some of the larger more significant systems which also represent various types of PV pumping applications.

LIST OF IDENTIFIED PV WATER PUMPING PROJECTS

Dec.1988

ernational

LOCATION	ARRAY	APPLICATION	RECORD NO.
evetogne,Rochefort	31500 Wp		32001
iti Island,Italy	32500 Wp	RO dessalination	32002
pathos,Is.,Greece	10000 Wp	irrigation	32003
nosa,Island,Italy	31500 Wp	RO dessalination	32004
long, Sanpaloc	224 Wp	school drinking water	32005
belli,Italy	70000 Wp	Municipal water	32006
, Manchina,Italy	3000 Wp		32007
stel,Portziano,It	750 Wp	water pumping	32008
at City, Egypt	3000 Wp	water lifting	32009
t Oweinat	3000 Wp	water lifting	32010
st Oweinat	18000 Wp	water lifting & dist.	32011
sounya	1850 Wp	irrigation pump	32012
Ghossoun	8300 Wp	desalination	32013
gh Tension Laborat	7000 Wp	water purification	32014
-P awein	18300 Wp	desalination 2000ppm	32015
,Indonesia	5500 Wp	irrigation	32016
uis, Indonesia	25000 Wp	ice making & RO desalin.	32017
llu Watu Sumba	5760 Wp	village pumping	32018
da,Sumba,Ind.	3650 Wp	water pumping	32019
Muu, Indonesia	3650 Wp	village pumping	32020
guia-Bougandji	1760 Wp	water pumping	32021
lossoville, Gabon	3200 Wp	water pumping	32022
,Senegal	810 Wp	village pump	32023
ia	720 Wp	village pumping	32024
dia	720 Wp	village pumping	32025
a	1440 Wp	village pumping	32026
aye,Bukina Fosa	1800 Wp	water pumping	32027
saisa Egypt	500 Wp	village pumping	32028
isa Egypt	350 Wp	village pumping	32029
isa Egypt	250 Wp	village pumping	32030

TABLE 3.2-1
INTERNATIONAL PV PUMPING PROJECTS

More detailed project reports on the above will be found in Appendix D.

3.3 - Major Participants

The major participants in the PV water pumping technology come from the various aspects of the solar industry. Most of the major photovoltaic module manufacturers have developed experience in water pumping installations as they obviously have a keen interest in this potentially large market for their product. Listed below are the manufacturers of modules who have been extensively involved in PV water pumping installations.

AEG - Germany
Solarex - U.S./Australia
Arco - U.S.
Mobile - U.S.
Kyocera - Japan
Heliodinamica - Brazil
Chronar/Trisolar - U.S.
CEL - India
BP Solar - U.K./Spain

In addition to the module manufacturers a number of system houses who specialize in the design and supply of PV power systems have also developed extensive experience in providing PV powered pumping systems. Some of the major such houses are:

Trisolar - U.S.A.
Solapak - U.K.
Southern Cross - Australia
Photocom - U.S.A.
SEI - Malta
R & S - Netherlands

From the pumping end of the systems, a number of major pump manufacturers have developed specialized products for use with photovoltaic power sources and some of the more notable firms are:

Grundfos - Denmark - submersible AC pump
KSB - Germany - DC centrifugal
Jacuzzi - U.S.A./Canada - DC submersible (discontinued)
- AC submersible (6)
A.Y. MacDonald -U.S.A.- DC submersible units
LeRoy Somer - France -DC surface motor
Guinard -France - surface motor
Mono Pumps - U.K. - submerged progressive cavity
Moyno -U.S./Canada - submerged progressive cavity

During the updating work on the World Bank Report (4) on PV water pumping performed by IT Power Limited in 1986, tenders were called for a number of photovoltaic powered pumping systems from a total of approximately forty suppliers throughout the world for specific systems. A summary of the responses of this tender call is given in Table 4.0-4 and includes a number of the above mentioned firms.

Published addresses and contacts for these participants are included in Appendix C.

There is a significant ground water industry active throughout the world and a number of major conferences are held periodically on various aspects of ground water supply. Many specialized conferences are held and a number of Canadians are very active in the organization and hosting of these various conferences. A listing of a number of these conferences is given in Table 3.3-2 for reference. A more complete list and further details will be found in Appendix B as part of the IT Power visit report.

30 May - 3 June 1988 Ottawa, Canada IWRA Congress 1988: Water for World Development: Education and Training

5-11 June 1988 Toronto, Canada
Symposium on Advances in Reverse Osmosis and Ultrafiltration

6-11 June 1988 Vysoke Tatry,Czechoslovakia
Hydrology of Mountainous Areas

9-10 June 1988 Toronto, Canada
8th International Symposium on Environmental Pollution

12-14 June 1988 Newfoundland, Canada
Third National Conference on Drinking Water

12-16 September 1988 Wuhan, China
Irrigation Evaluation & Water Management Conference

14-16 September /88 Delft, The Netherlands

Expert Meeting on New Developments in Groundwater Modelling

4-10 October 1988 Karlsruhe, West Germany
4th Pump Congress

23-28 October 1988 Albury-Wodonga,Australia
Fourth International Micro-Irrigation Congress

7-12 November 1988 Ouagadougou, Burkina Fasco
Hydrology and Hydrogeology in Arid and Semi-Arid Areas of Africa

10-11 November 1988 Bombay, India
Water Pollution & Environmental Control

16-18 November 1988 Tampa, Florida, USA
Advances in Groundwater Hydrology

23-24 November 1988 London, UK
Advances in Slow Sand Filtration

12-15 December, 1988 Las Vegas, USA
NWWA National Convention and Exposition
Covers all groundwater topics.

17-19 April 1989 Cambridge, England
Pumping: New Challenges - Where Next?

25-26 May 1989 Srinagar, Kashmir, India
Air/Water & Environmental Pollution & Hazardous Wastes

8-9 June 1989 Toronto, Canada
9th International Symposium on Environmental Pollution

11-13 September 1989 Houston, USA
NWWA National Convention

14-16 November 1989 London, UK
World Water 89 Congress

TABLE 3.3-2
"WATER CONFERENCES & EXHIBITIONS 1988-1989"

Many aid groups are involved in utilizing PV power water pumps to play a role in their humanitarian programs, primarily in third world countries. With the maturing of the technology for PV pumps and the appreciation of the reliability and cost effectiveness of these systems a number of major programs are now being planned.

Three groups in particular are mentioned here to illustrate the type of programs being developed.

The first is the Canadian International Development Agency (CIDA) which has called tenders and is presently assessing the responses for a program to supply PV powered water pumps for Morocco. An intitial call was for thirty-five pumps with a potential of two hundred and twenty-five units to be ordered for this program.

The second program is one currently being planned by the European Economic Community calling for the installation of some thirteen hundred pump units throughout west Africa. The pre-qualification of suppliers has developed a short list of ten qualified consortia or firms to bid on this project, tenders for which are expected to be called by early 1989.

The third group is Mali Aqua Viva which is a charitable group operating within Mali with the specific aim of providing potable water to the villagers. They presently have some eighty pump installations in operation throughout the southern part of the West African country of Mali and a well organized maintenance and operational team to service the program. A list of their installations is included in Appendix D.

R&D work on PV pumping systems is being carried out in a number of countries including Canada with major work presently being done in Germany, Italy and Japan. This activity reflects somewhat the level of government funding provided for solar research in the respective countries. The U.S. and France have been very active in the past but with current funding restrictions their activities are now less extensive.

4.0 -- CURRENT ECONOMICS

In considering the question of current economics for PV water pumping systems two aspects emerge. The first is the absolute cost of the systems and the second is the relative cost of the systems to alternative methods of pumping. The main alternative sources of power for pumping are the diesel set, wind pumps and handpumps.

While several major studies have been performed in the past few years on the cost of PV water pumping systems, a commercial quotation is, of course, the final definition of actual cost for any actual application. The figures quoted in this section are from the reports as referenced and are provided here for cost comparisons and to establish guidelines for producers and users.

The "cost" of PV pumping systems can be expressed in a number of ways and the most common is the figure of dollars per peak watt of the solar array. This is simply the total cost of the PV system divided by the number of peak watts (Wp) in the array rating. When considering these figures it should be recalled that the method of rating the system with "Specific Capital Cost" (SCC) is a better figure for comparing two PV systems as it relates the cost to the efficiency as well. Additionally any quoted figures should be clarified as to whether they are equipment only, at the factory or delivered, or whether the price refers to an installed system on site.

The following table 4.0-1 presents the approximate 1988 prices for a typical size range of solar pump configuration as listed.

Motor Pump/configuration	Output (m^3/day) @ 5kWhm/cu.m/day insolation	Head (m)	Solar Array (Wp)	System Price US$ FOB
a) Submerged borehole motor pump	40	20	1200	7.000-8.000
b) Surface motor/ submerged pump	60	7	340	5.000-6.000
c) Reciprocating positive displacement pump	6	100	1200	7.500-9.000
d) Floating motor/pumpset	100 10	3 3	530 85	4.000 2.000
e) Surface suction pump	40	4	350	3.000

TABLE 4.0-1
APPROXIMATE 1983 PRICE FOR PV PUMPING SYSTEMS(8)

The systems with the larger array sizes generally have lower cost per /Wp. The above figures represents a range of cost from $7.00 to $15.00/Wp.

Table 4.0-2 presents estimated installed costs of PV pump systems for various size arrays which were presented in a 1987 report by the Meridian Corporation.(9)

Array Power (Wp)	Array Costs (\$/Wp)[a]	Motor/Pump Costs (\$/Wp)
<200	8.00	7.00
200-500	7.75	4.25
500-1000	7.50	2.50
>1000	7.25[b]	b

Sources: I.T. Power Inc., A.Y. McDonald Mfg. Co., Chronar TriSolar, Inc. (1987).

a. Includes installation.
b. Cost is similar to conventional AC submersible motor/pump sets. When AC is used, $ 0.75/Wp is added to PV array cost for a DC/AC inverter.

TABLE 4.0-2
ESTIMATED COSTS OF INSTALLED PV PUMP SYSTEMS

A slightly different breakdown including projected costs of pumps is given in Table 4.0-3 which was presented in 1986 in the IT Power World Bank Report update. (5)

	Peak PV Array Power (watts)	Present (1986)	Potential 1993-1996
Module cost ($/Wp)	All	6	2
Motor Pump Subsystem ($/Wp)	200	6	4
	500	3.5	2.5
	1000	2.0	1.5
	2000	1.5	1.0
Installation Costs ($/Wp)	200	3	3
	500	2.5	2.5
	1000	2	2
	2000	1.5	1.5
Total Installed Cost ($/Wp)	200	15	9
	500	12	7
	1000	10	6
	2000	9	5

TABLE 4.0-3
PRESENT AND PROJECTED COSTS OF SOLAR PUMPS

These last two tables confirm the continuing downward trend of the pumping systems by indicating the reduction in the prices from 1986-1987. Figure 4.0-1 presents the historic, current, and projected, installed costs of solar pumps referenced to the previous table in 1986 dollars.

Figure 4.0-2 presents the historic and current costs of PV modules and pump prices in US (1988) dollars per peak Watt.

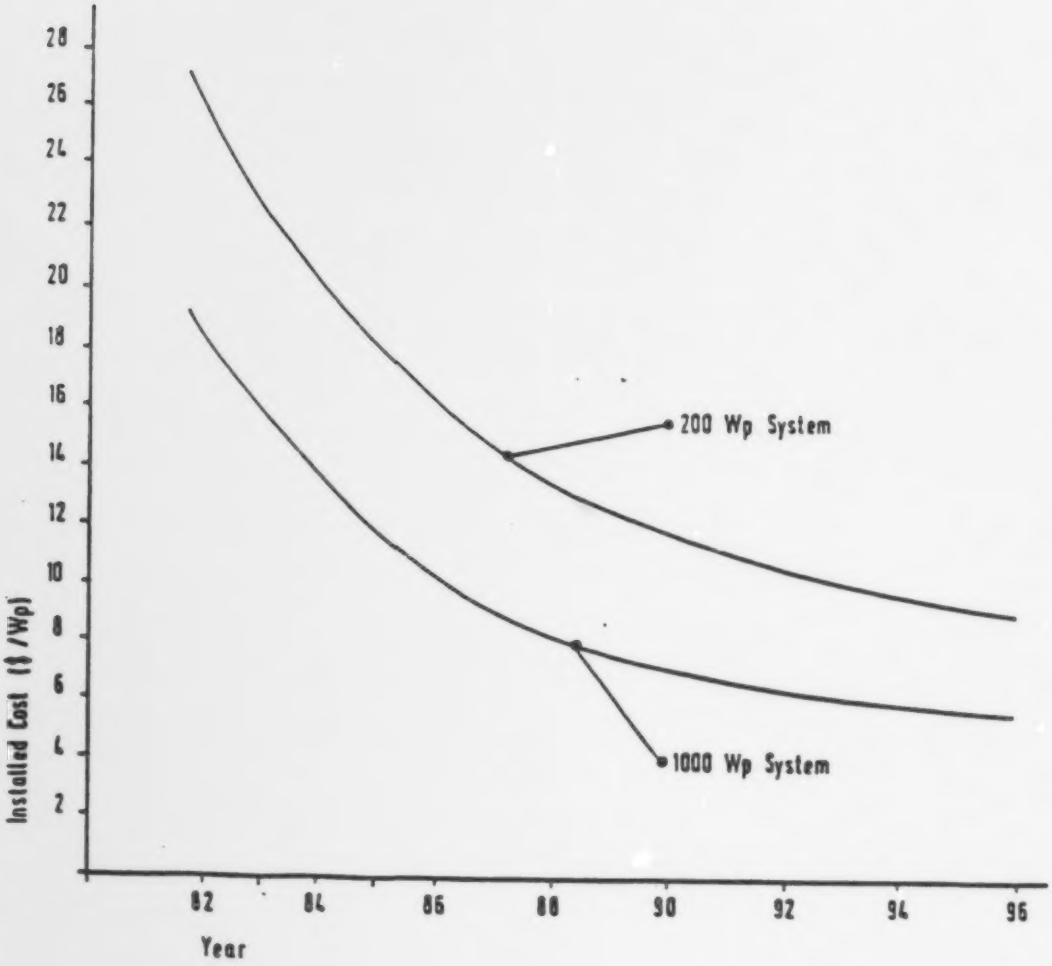


FIGURE 4.0-1
HISTORIC, CURRENT AND PROJECTED INSTALLED COSTS OF SOLAR PUMPS (Referenced to 1986 dollars)

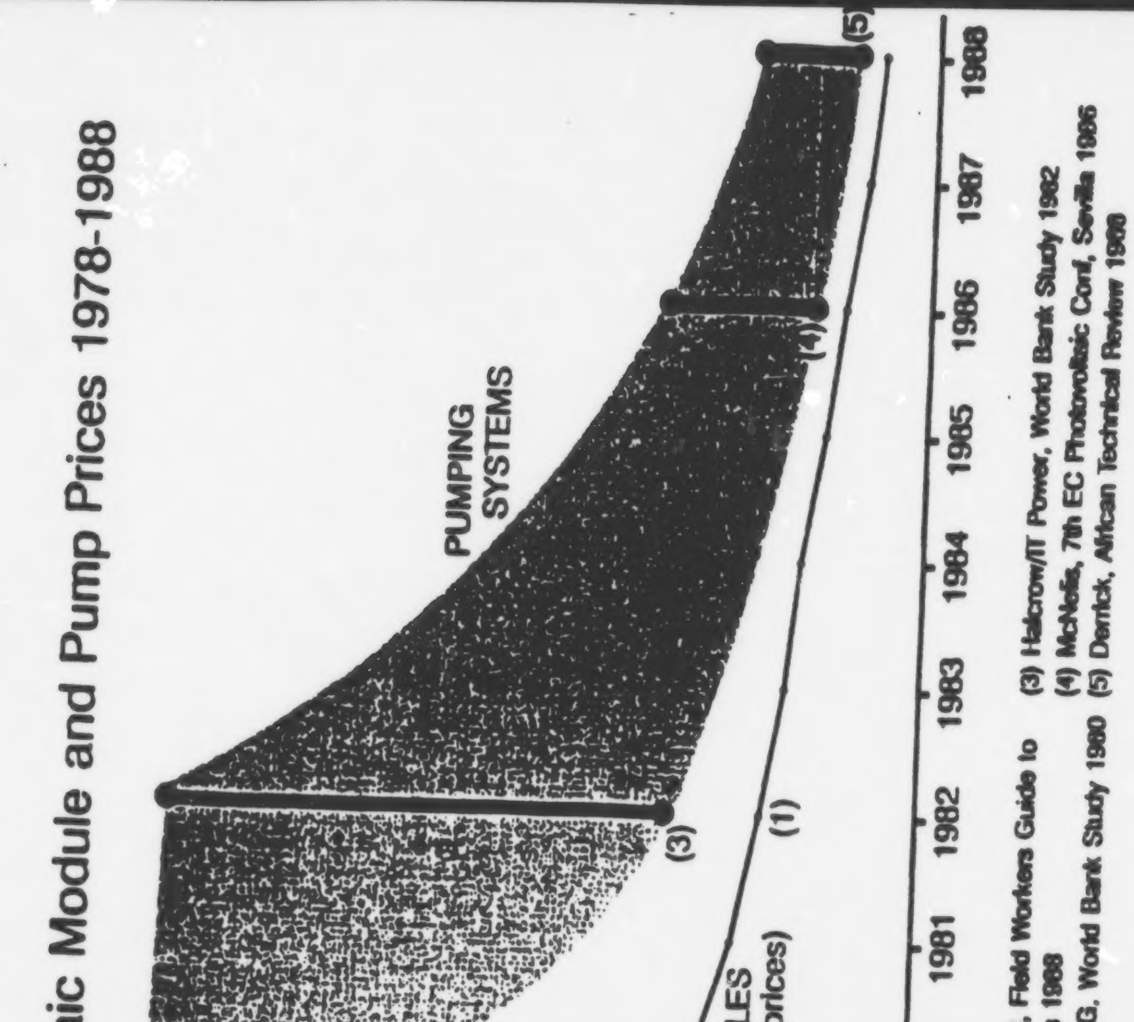


FIGURE 4.02
PHOTOVOLTAIC MODULE AND PUMP PRICES 1978-1988

For references purposes Table 4.0-4 list a detailed number of quotations received in response to a 1985 enquiry.

SUPPLIER	SYSTEM PRICES (F.O.B) AND SUBSYSTEM TYPE											
	60m³/d x 2m			60m³/d x 7m			20m³/d x 20m			40m³/d x 40m		
	$ total	$/Wp	$/m⁴	$ total	$/Wp	$/m⁴	$ total	$/Wp	$/m⁴	$ total	$/Wp	$/m⁴
ALZETTE	7220	16.2	60.2	12930	13.3	30.8	10950	13.7	27.4	25770	11.0	16.2
	AC + battery Centrifugal in line			AC + battery Centrifugal in line			AC Submersible			AC Submersible		
BP SOLAR	3070	11.6	25.6	5410	10.3	12.9	7310	10.6	18.3			
	DC brushless KSB Aquasol			DC brushless KSB Aquasol			AC Grundfos Submersible					
EBARA	9760	16.3	81.3	15700	16.2	37.4	18300	15.2	45.8	57900	12.0	36.2
	DC brushless Submersible			DC brushless Submersible			AC Submersible			AC Submersible		
GRUNDFOS				9290	12.3	22.1	9180	12.4	23.0	17670	6.0	11.0
				AC Centrifugal			AC Centrifugal			AC Submersible		
KOMATSU	8050	15.3	67.1	11070	10.0	26.4	23140	13.1	57.9	48300	10.2	30.2
	DC Submersible			DC Submersible			DC Submersible			DC Submersible		
KSB	4200	16.3	35.0	7130	13.9	17.0						
	DC Aquasol			DC Aquasol								
KYOCERA	5110		42.6	7540		18.0	9830	12.1	24.6			
	DC brushless			DC			AC Grundfos Submersible					
A.T. McDONALD	6150	6.9	51.3	7950	7.7	18.9	9450	11.0	23.6			
	DC Centrifugal			DC Centrifugal			DC brushless Submersible					
MONO PUMPS				9670	15.2	23.0	6990	16.5	17.5			
				DC + MPPT Pos. Disp. Rotary			DC + MPPT Pos. Disp. Rotary					
SEI	3790	17.6	31.6	4665	12.7	11.1						
	DC KSB Aquasol			DC KSB Aquasol								
SES	4710	16.7	39.3	6950	12.3	16.6	6750	12.0	16.9			
	DC Jacuzzi Submersible			DC Jacuzzi Submersible			DC Jacuzzi Submersible					
S. INTERNATIONAL	6220	23.9	51.8	11530	15.3	27.5	10320	16.1	25.8			
	DC brushless Centrifugal			DC brushless Centrifugal			DC brushless Centrifugal					
SOLAPAK	4540		37.8	8660		20.6	8660		21.7	28070		17.6
	DC Centrifugal			AC Centrifugal			AC Multistage Centrifugal			AC Multistage Centrifugal		
SOLAREX	4490	13.4	37.5	6690	10.6	15.9	8920	8.9	22.3	15200	9.5	9.5
	DC Jacuzzi Submersible			DC Jacuzzi Submersible			DC Jacuzzi Submersible			DC Jacuzzi Submersible		
SOLAR ENERGIE TECHNIK	7210	13.1	60.1	7210	13.1	17.2	11680	13.9	29.2	22020	11.0	13.8
	AC			AC			AC			AC		
TOTAL ENERGIE DEVELOPMENT				11970	18.7	28.5	1630	17.3	41.6			
				AC Submersible/Floating			AC Submersible					
TPE	3200	13.2	26.7	10500	16.7	25.0	12870	16.1	32.2			
	DC Centrifugal			DC Jacuzzi Submersible			DC Jacuzzi Submersible					

TABLE 4.0-4
1985 PV PUMP QUOTATIONS

In analyzing and comparing quotations between various types of systems for use in third world countries, the effect of internal taxes and subsidies can affect considerably the comparative costs of two technologies. For this reason a concept of "border pricing" has been developed by IT Power to reflect the actual competitive costs of the hardware itself as it enters the country without considerations of internal duties and taxes. This is intended to reflect the technical competitiveness of the systems as opposed to the political competetiveness of the various systems.

A distinction is made considering the cost of PV pumping systems for village water as opposed to irrigation applications, as water for irrigation is often characterized by a large variation in demand from month to month. The solar pump to meet the peak demand is thus normally under utilized in the other months. This leads to a less competitive position for the PV pumps relative to the diesel system.

Attempts have been made in some reports to define the value of water to various sectors and relate the cost of PV pumping system to an actual cost of water per cubic metre delivered. In the 1981 World Bank study (1) a figure of $.06 per cubic metre was quoted. In actual fact however, the question is usually a relative one in that where the water is required, the cost of the system is generally measured relative to the cost of an alternative system to do the same required job. Thus in Pakistan where diesel sets are very inexpensive, a diesel cost of 9.4 cents per cubic metre is still acceptable relative to a solar system cost of approximately 13 cents per cubic metre. (12)

The cost question then becomes a relative cost comparison between the PV pumping systems and a competing alternative.

Figure 4.0-3 illustrates graphically the competitive areas for village water supply between diesel and PV pumping systems. The range is given in these graphs for both 1986 and 1996 for two different sites, one with 4 kw hours /m2 per day insolation and the other with 5.5.

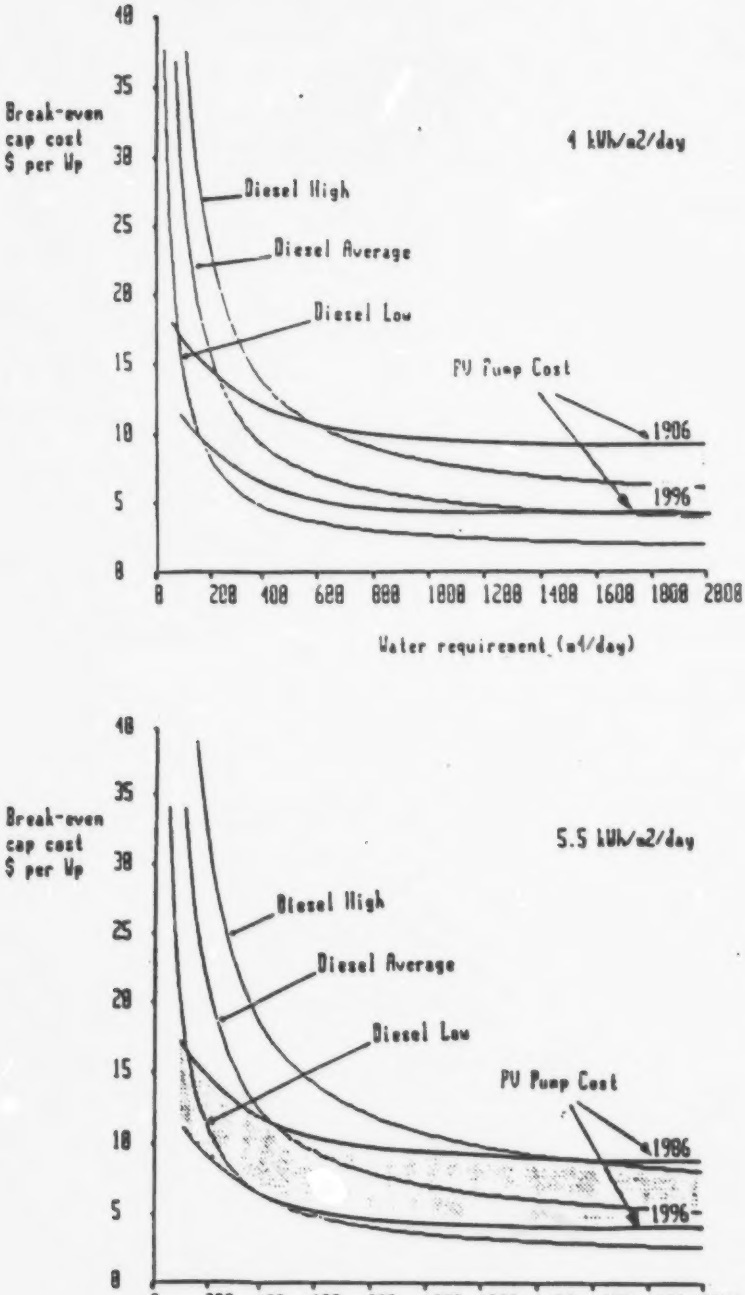


FIGURE 4.0-3
SOLAR PUMP COMPETITIVENESS FOR VILLAGE WATER SUPPLY(8)

On the following pages Figures 4.0-4 and 4.0-5 compare the unit water costs of solar and diesel and also solar and wind pumps for various system costs and insolation locations. Again in these graphs the concept of m4, the product of the volume times the head is utilized on the x axis of the graphs.

Table 4.0-5 presents the figures for the capabilities of the competitiveness of solar pumps in a tabular format. The irrigation figures are based on a peak demand factor (PDF) of two which represents the ratio of the peak daily water demand to the average daily demand.

YEAR:		1986		1996	
APPLICATION	DIESEL OPERATING COST	CRITICAL MONTH INSOLATION ($kWh/m^2/day$)			
		4	5.5	4	5.5
RURAL WATER SUPPLY	HIGH	600	1500	>2000	>2000
	AVERAGE	250	500	1500	>2000
	LOW	120	160	180	600
IRRIGATION (PDF = 2)	HIGH	160	250	600	1700
	AVERAGE	100	150	170	250
	LOW	50	60	60	100

MAXIMUM SOLAR PUMP CAPACITIES (M^4/DAY) FOR COMPETITIVENESS WITH DIESEL PUMPS

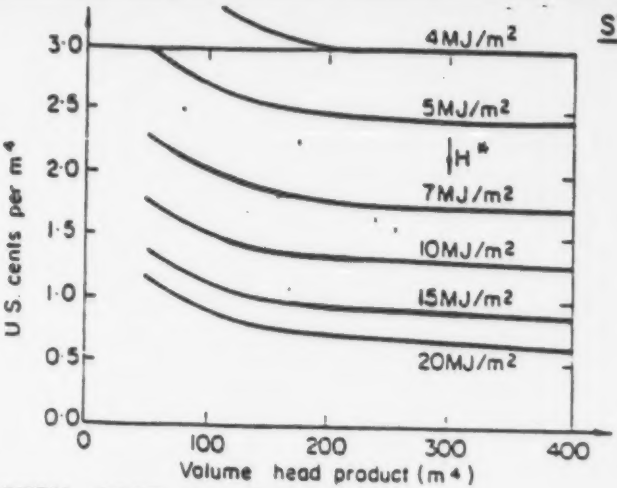
Note: PDF = ratio of peak daily water demand to average daily demand

TABLE 4.0-5
COMPETITIVENESS OF SOLAR PUMPS - CAPACITIES

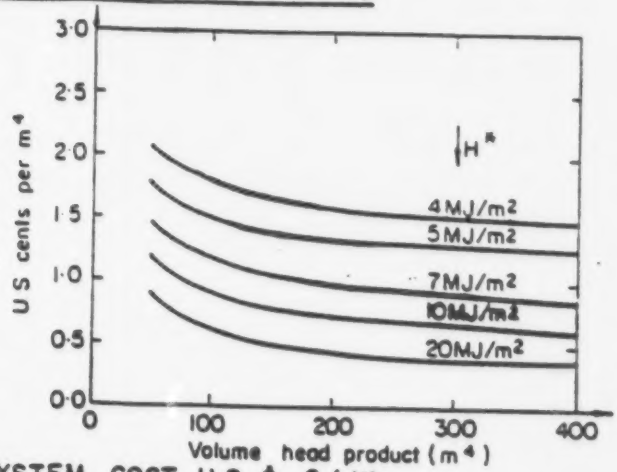
In summary we see that for most pumping applications a solar pump will be more expensive on a first cost basis than a diesel pump or other alternative pumping method. Based on life cycle costing however, conditions can clearly be recognized where solar pumps may provide water at the least unit water cost.

At present it is estimated that solar pumps are typically cost competitive, compared with diesels, for rural water water supply applications up to approximately 800m4/day capacity (eg.40 m/day and 20 m head). In areas of high diesel pump operating costs, solar pumps can be competitive up to 2500 m4.

SYSTEM COST U.S. $ 18 / Wp



SYSTEM COST U.S. $ 9 / Wp



SYSTEM COST U.S. $ 6 / Wp

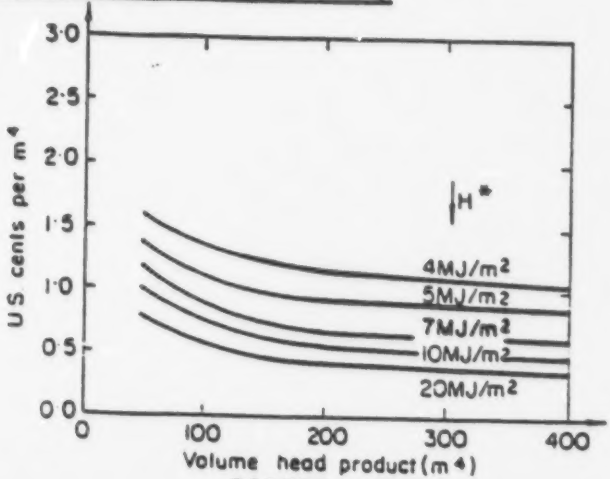
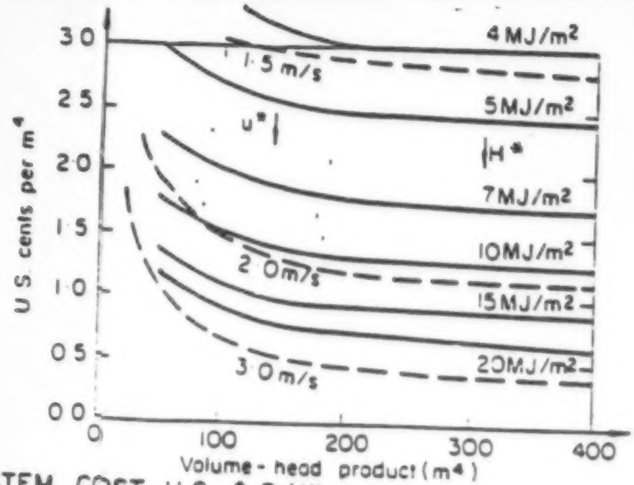
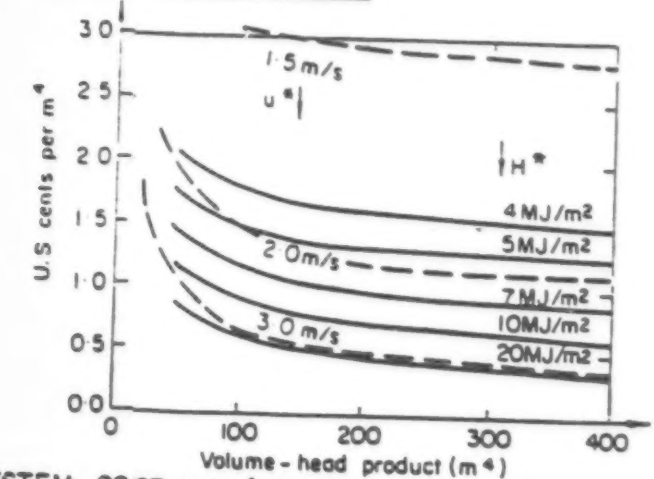


FIGURE 4.0-4
COMPARISON OF UNIT WATER COSTS BETWEEN SOLAR AND DIESEL PUMPS (8)

COST U.S $18 / Wp



SYSTEM COST U.S. $ 9 / Wp



SYSTEM COST U.S. $ 6 / Wp

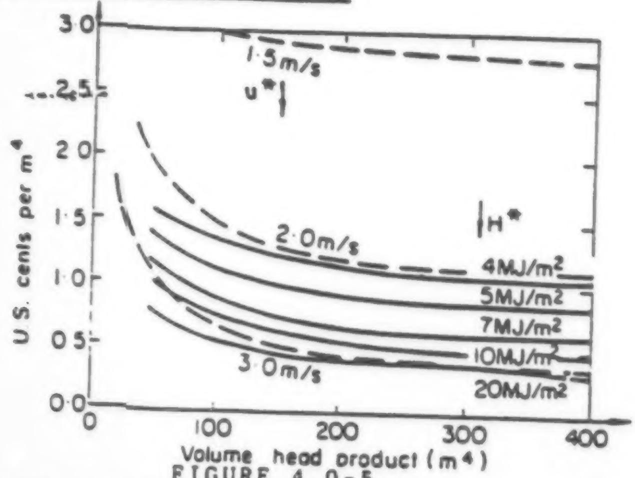


FIGURE 4.0-5
COMPARISON OF UNIT WATER COSTS BETWEEN SOLAR AND WIND PUMPS (8)

For irrigation, solar pumps are currently only cost effective up to 250 m4/day capacity.

By 1996 if solar photovoltaic pumps systems fall to $4.5 per watt peak (installed) they could be typically competitive for water supply applications up to 2000 m4/day or more (3 kWp array) and for irrigation and areas of high diesel operating costs up to 1700 m4/day (2 kWp array).

The costs of solar arrays and consequently solar pump systems are continuing to decrease and by 1996 there is potential for costs to fall as a result of increased volume of sales and lower prices to an installed cost of approximately $5.00 - $9.00/watt peak.

5.0 - TRENDS AND POTENTIAL MARKETS

One of the major trends observed has been the emergence of the Grundfos stainless steel AC driven submersible pump as being a preferred unit for reliability by a number of organizations. This is seen in the conversion of older units in the Mali Aqua Viva project and the Morocco tender called by CIDA. The main attributes are the reliability and the relative ease of installation with the lack of required maintenance.

Floating DC pumps for smaller and lower head applications are also being installed in greater numbers. A general trend toward eliminating brushed DC motors is obvious as the preference for the DC brushless technology grows.

In the application end, the reported trends are to deliver the PV pump systems in larger packages as evidence by the CIDA and EEC projects. This is as opposed to a multiplicity of smaller individual projects by these larger aid organizations. The smaller aid and missionary groups undoubtedly will continue to be a continuing market with their smaller targeted applications for specific but dispersed sites.

A concept developed in the Mali Aqua Viva project and now receiving increased support and adoption by other agencies is the provision and requirement of increased financial and time contribution from the recipients where PV pumps are supplied on an aid basis. Their experiences have indicated that this increased participation by the community tends to ensure a much more satisfactory operational program for the pumping units. The Mali program is now receiving 25% total funding from the local recipient communities.

The recognition is growing that for potable water to be practical and healthful, it must not only be pumped but in many cases it must also be treated to ensure that it is healthy and free of contamination. A trend to the inclusion of water treatment facilities with sand filters or UV exposure has been reported and is expected to continue to become a more widespread requirement.

In the R&D side of PV water pumping, work has been progressing in a number of organizations for the development of AC controller/inverters to interface solar arrays with submerged AC pump motors. Several research groups have identified the possibilities of increased pumping efficiency by the use of progressive cavity rotary positive displacement pumps. Two groups in particular are working on development of eliminating the long surface to water power shaft by incorporating a submerged motor with the pumping portion of the unit. A Canadian group, Peter Ward & Associates is working on a submersible DC motor (13) while a German group is working on a submersible AC drive motor to provide the down hole power for these pumps. (15)

The National Renewable Energy Programs of Germany, Italy, France, Japan and the CEC all have segments devoted to improving the efficiency of solar powered water pumps.

There is a developing market for components of PV pumping systems. Initially the major module companies and the pump companies developed pump systems and were marketing only the complete systems including the pumps and the modules rather than the specialized components. This was evident in the early restricted availability of pumps manufactured by KSB, Grundfos and Total. With the expanding market and the desire to increase the distribution of their products the pump components are now being widely marketed separately and are being made available much more readily to the system houses.

While some commercial markets are developing, the financing of most present pump installations is being provided by public money or aid money from various sources. There are unfortunately few of the third world villages who are able to purchase PV pumping systems commercially entirely on their own resources. Thus while the sales of PV pump systems will continue to increase most of the financing will be provided by various aid groups and in many cases this aid will be tied to the donor's trade resources where possible. Thus in order to participate in a large aid program such as the EEC project in West Africa, a joint venture will be necessary for Canadian producers in order to have their products involved.

While the current major application for PV pumping is providing potable water to remote villages, the ultimate long term market is visualized as providing water for irrigation. A tremendous market potential exists in southeast Asia where literally millions of small farmers rely on irrigation for their small land holdings to maximize their crops. Presently many of these are utilizing other forms of pumping such as the internal combustion engine. To penetrate this market the PV pumping systems must be reduced in cost in order to be competetive. These systems will probably be portable and will be smaller in size than many of the village water systems. The volume of users however, will provide a much larger demand and subsequent market than the potable water application.

A recent 1987 report by Meridian Corporation and IT Power (9) has provided estimates of the potential market for rural PV water supply systems throughout the world. These estimates are presented in the following tables 5.0-1 and 5.0-2 and indicate a potential market of 194,000 villages appropriate for PV systems averaging 1453 Wp in array size. This indicates a total potential market in the range of 250-280 MWp of PV for rural water supply applications.

These estimates are based on the water demand in litres per capita daily (LPCD) as indicated in column 3 of Table 5.0-2.

REGION	A RURAL POPLTN. WITHOUT SAFE WATER ACCESS (MILLIONS)	B ESTIMATED REGIONAL WELL COST ($)	C ASSUMED POPULATION IN AREAS WATER TABLE >10M (MILL.)	D WORST MONTH ISOLTN. KWH/M2/DAY	E PREFERRED WATER USE RATE (LPCD)	F PV COST COMPETITIVE VILLAGE SIZE (PERSONS)
ANDEAN COUNTRIES	13	2500	10	5	40	75-800
CENTRAL AMERICA & CARIBBEAN	32	2500	10	4	40	75-500
EQUATORIAL AFRICA	68	5000	41	5	20	500-2000
EASTERN & SOUTHERN AFRICA	64	2500	32	5	20	1000-2000
FAR EAST & THE PACIFIC	200	2500	80	5	40	75-800
INDIAN SUBCONTINENT	412	1500	124	5	40	200-800
LATIN AMERICA (N.E.C.)*	20	2500	10	4	40	75-500
MIDDLE EAST & NORTH AFRICA	110	2500	83	4	20	1200-2000
SAHEL	10	5000	9	6	20	250-2500
TOTAL	928		357			

REGION	NOTES--> G % POP. IN VILLAGES WHERE PV COMPETV.	H POTENTIAL POPULATION SERVED BY PV SYST. (MILLIONS)	J POTENTIAL POPULATION SERVED BY HAND PUMPS (MILLIONS)	K POTENTIAL POPULATION SERVED BY DIESELS (MILLIONS)	L MAXIMUM EQUIVALENT PV NEEDED MWp
ANDEAN COUNTRIES	40	4	4	5	9
CENTRAL AMERICA & CARIBBEAN	14	1	23	8	4
EQUATORIAL AFRICA	58	24	35	10	25
EASTERN & SOUTHERN AFRICA	32	10	46	8	12
FAR EAST & THE PACIFIC	40	32	123	45	78
INDIAN SUBCONTINENT	30	37	293	82	90
LATIN AMERICA (N.E.C.)	14	1	10	8	4
MIDDLE EAST & NORTH AFRICA	25	21	64	26	31
SAHEL	82	7	1	1	7
TOTAL		137	599	192	264

Notes:

A. 1983 estimate, China is not included due to lack of data. Source: Report of the Secretary General to the UN to the Economic and Social Council of the UN General Assembly, "Progress in the Attainment of the International Drinking Water Supply and Sanitation Decade," A/40/108, March 1985.

B. Source: UNDP/World Bank Handpump Project and author estimates

C. Author estimates, based on knowledge of regional water table characteristics and on assumption that majority of rural persons live in areas where water table is shallow.

D. From worst month insolation profile map developed by UNICEF (EPI Product Catalog, 1986).

E. Source: World Bank, Village Water Supply, 1984.

F. Estimated from analysis results shown in Exhibits 5-4 and 5-5 using regional characterizations given in columns B, D, and E

G. Based on village population distributions in India reported in. Roche, Robert. The Impact of Water Quality and Water Quantity on Health in Rural Communities in Developing Countries, Ph.D. Dissertation, University of California at Berkeley, California 1985 Indian data used in the absence of data from other countries or regions.

H. (Column G) * (Column C)/100

J. (Column A) - (Column C)* (fraction of population in villages smaller than village size lower limit in Column F) Village size distributions from Dr. Roche.

K. (Column A)-(Column H)-(Column J)

L. 9.81*(30 m)*(Column E)/1000*(Column H)/[3.6*(PV pump eff)*(PV BOS eff)*(Column D)]

* *N.E.C. - Not elsewhere considered.*

TABLE 5.0-1

ESTIMATES OF MARKETS FOR PV WATER PUMPING SYSTEMS

TABLE 5.0-2
ESTIMATE OF P.V. PUMPING SYSTEM SPECIFICATION

EXHIBIT 5-12
PRELIMINARY ESTIMATE OF PV PUMPING SYSTEM SPECIFICATIONS

	A	A	B	C	D	E
REGION	INSOLATION KWH/M2/DAY	WATER DEMAND (LPCD)	AVERAGE VILLAGE SIZE (# OF PERSONS)	AVERAGE PV POWER SYSTEM SIZE Wp	AVERAGE WATER DEMAND M3/DAY PER VILLAGE	TOTAL NO. OF VILLAGES #
ANDEAN COUNTRIES	5	40	500	1211	20	8000
CENTRAL AMERICA & CARIBBEAN	4	40	300	908	12	3333
EQUATORIAL AFRICA	5	20	1300	1574	26	18462
EAST AFRICA	5	20	1500	1817	30	6667
FAR EAST AND PACIFIC	5	40	500	1211	20	64000
INDIAN SUBCONTINENT	5	40	500	1211	20	74000
LATIN AMERICA (N.E.C.)*	4	40	300	908	12	3333
MIDDLE EAST	4	20	1800	2725	36	11667
SAHEL	6	20	1500	1514	30	4667
TOTAL/AVERAGE			706	1453	22	194128
MINIMUM			300	908	12	
MAXIMUM			1800	2725	36	

NOTES:
A. FROM MARKET POTENTIAL ESTIMATION TABLE (EXHIBIT 5-9).
B. AVERAGE OF VILLAGE SIZE RANGE IN EXHIBIT 5-9.
C. ESTIMATED AS IN COLUMN L IN EXHIBIT 5-9
D. VILLAGE SIZE TIMES PER CAPITA DEMAND
E. POTENTIAL POPULATION SERVED BY PV (COLUMN H IN EXHIBIT 5-9)/VILLAGE SIZE.
* N.E.C. - NOT ELSEWHERE CONSIDERED

5.1 - List of Funding Agencies

During the review of literature the following aid groups were reported to been involved in the installation of PV powered water pumping systems.

AFRICARE
ARD - ASSOCIATES IN RURAL DEVELOPMENT
CARE
CATHOLIC RELIEF
JARS - JUNGLE AVIATION RADIO SERVICE (U.S.A.)
OAS - ORGANIZATION OF AMERICAN STATES
PAHO
VITA

A list of "Sources of Information on Renewable Energy Sources in Applications for Small Scale Water Supply Systems" is enclosed in Appendix E from a recent report from the International Reference Centre for Community Supply and Sanitation. (11)

This is a fairly extensive list of agencies in the various countries that are involved with renewable energy sources and water pumping in particular. It is not however, necessarily complete nor are these agencies necessarily funding installations.

6.0 - CONCLUSIONS AND RECOMMENDATIONS

Photovoltaic powered water pumping systems are today technically viable for practically all applications. They have been proven reliable and for the popular applications of village water supply, the solar to hydraulic efficiency is generally in the 4% range with array efficiencies of 12% and pump motor set efficiencies in the 30-40% range.

Today photovoltaic powered systems are economically competitive with diesel pump sets up to 800 m4 and up to 2500 m4 in higher fuel cost areas. They are not yet economically competetive in all market segments with handpumps, wind and diesel pumping systems still being more cost effective in certain applications. The main competition is diesel powered water pumps.

Prices of the solar array component have been continually decreasing and their continued decrease along with improved efficiencies in the other components forecast future lower costs overall for PV water pumping systems.

A very large market demand has been identified for village water pumping applications in the order of 195,000 units over the next twenty years. (9). The potential users today however, are unable to pay for these systems. Essentially International aid programs will determine the dollars that will be spent on these programs in the near future.

A massive low lift irrigation market potential is seen in the far east area where small farmers will be able to purchase pumps for their own use when market prices are in the $1.00 per watt peak range and system prices of $300.00 are feasible. As one PV pump system can supply the equivalent of probably five handpump bore holes there appears to be a considerable potential for solarizing handpump installations as the existing millions of hand-pumps require replacement.

The non government organizations (NGO's) and funding agencies throughout the world are exhibiting an increasing awareness of the PV water pumping technology. In their programs they are recognizing the need for a critical mass of a pumping aid program and it has been suggested that a ten year committment is appropriate to ensure that the results will be optimized. This is necessary to ensure an appropriate infrastructure in the host country along with the appropriate socio-economic considerations. A minimum number of twenty similar pumping installations is suggested to provide an appropriate base for proper training of maintenance personnel and workshop requirements. Funds should be provided to assure that a maintenance program can be established and maintained. It is recognized that some aid programs will have trade ties to the donor country.

The need for appropriate water treatment to ensure healthful water has been recognized and the integration of slow sand filtration and UV treatments is becoming more widespread and will be more commonly integrated into future systems.

There is currently throughout the world an international technology base of equipment suppliers and system houses able to provide reliable equipment and systems for photovoltaic powered water pumping systems. (8)

There is also international recognition of the PV pumping technology as a component of national renewable energy programs as a result of which the major national programs include a component for the support of the development and improvement of PV water pumping systems.

The pumping technology that is currently most popular is the submerged multi-stage centrifugal pump powered by an AC motor and utilizing appropriate inverter/controller components. Ease of installation, security of pump and motor, and reliability due to cooler operating temperatures of the submersed motor, have all been factors in creating this preference. A collapsible reinforced plastic hose for the downhole portion of these systems versus rigid pipe has become an acceptable concept.

The general conclusion is that a higher quality pump is worth additional initial cost due to the extended reliability under remote operational environments. System design experience expertise is being developed in a number of commercial firms and institutions and the quality of installations has been improving continually.

For new pump types and pumping systems, field test programs independently monitored are recommended before widespread installation is attempted. While assurance of proper installation in a field test is desired, it has been suggested that a new system package as proposed for shipment, should be installed by field personnel who are unskilled and who would be more typical of the offshore recipients than the manufacturers production or installation crew. This will enable minor installation problems to be identified and resolved before shipment and thus facilitate the eventual offshore installation.

For remote installation considerations, the following items have been recommended:

- All cabling should be protected and be termite proof where appropriate. Armoured cable is necessary in some cases to resist mice such as in Australia.
- Security fencing around the surface installation should be recommended.
- All cable lengths should be reduced to a minimum.
- Submerged motors are preferred for cooler operating temperatures and security of hardware. They also are better adaptable to bent bore holes.
- Four inch pumps are more flexible in that two four inch pumps can be utilized in a six inch bore hole, one above the other.
- Components should be crated for movement by Land Rover type vehicles with maximum crate length approximately six feet so that complete installation hardware can be accommodated with one trip if possible.
- Safety awareness should be emphasized where high voltage components are utilized. Familiarity with 12 volt systems could lead to complacency in dealing with any high voltage electrical circuits with unfortunate consequences.
- Operating and maintenance manuals in the local language incorporating accurate translation from English/ French.

General recommendations are as follows for the general development of the industry:

- Identify aid groups - it would be particularily useful to identify those aid organizations who are now or have potential for funding PV water pumping systems throughout the third world developing countries. It would be particularily useful to identify the specific aid groups working within a given territory in order to assist in co-ordinating their activities such as has been done in Kenya with the Kengo Association of NGO groups.

- Evaluate the relative merits of the various computer simulation models for PV water pumping presently available.

- Encourage and support R&D in the following areas:

  - controls
  - DC submersible motors
  - motor efficiency
  - independent field trials and testing with appropriate monitoring

- Involve the ground water industry in proposed projects to access their expertise in the quality/treatment issues of the water delivery.

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APPENDIX A

BIBLIOGRAPHY AND TECHNICAL DATA

- Bibliography
- Technical Data (Jacuzzi)
    - Conversion Factors
    - Pump Capacity
    - Pump Performance
    - Suction Lift
    - Work Energy Power and Efficiency

APPENDIX A - BIBLIOGRAPHY

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JACUZZI®

PUMPS AND WATER SYSTEMS

ENGINEERING
INFORMATION

TABLE 1 — DECIMAL EQUIVALENTS of inches in fractions in inches and millimetres

in.	1/64	1/32	3/64	1/16	5/64	3/32	7/64	1/8	9/64	5/32	11/64	3/16	13/64	7/32	15/64	1/4	in.
in	0.0156	0.0312	0.0469	0.0625	0.0781	0.0937	0.1094	0.1250	0.1406	0.1562	0.1719	0.1875	0.2031	0.2187	0.2344	0.2500	in
mm	0.3969	0.7937	1.1906	1.5875	1.9844	2.3812	2.7778	3.1750	3.5719	3.9687	4.3656	4.7625	5.1594	5.5562	5.9531	6.3500	mm
in.	**17/64**	**9/32**	**19/64**	**5/16**	**21/64**	**11/32**	**23/64**	**3/8**	**25/64**	**13/32**	**27/64**	**7/16**	**29/64**	**15/32**	**31/64**	**1/2**	**in.**
in	0.2656	0.2812	0.2969	0.3125	0.3281	0.3437	0.3594	0.3750	0.3906	0.4062	0.4219	0.4375	0.4531	0.4687	0.4844	0.5000	in
mm	6.7469	7.1437	7.5406	7.9375	8.3344	8.7312	9.1281	9.5250	9.9219	10.319	10.716	11.112	11.509	11.906	12.303	12.700	mm
in.	**33/64**	**17/32**	**35/64**	**9/16**	**37/64**	**19/32**	**39/64**	**5/8**	**41/64**	**21/32**	**43/64**	**11/16**	**45/64**	**23/32**	**47/64**	**3/4**	**in.**
in	0.5156	0.5312	0.5469	0.5625	0.5781	0.5937	0.6094	0.6250	0.6406	0.6562	0.6719	0.6875	0.7031	0.7187	0.7344	0.7500	in
mm	13.097	13.494	13.891	14.287	14.684	15.081	15.478	15.875	16.272	16.669	17.066	17.462	17.859	18.256	18.653	19.050	mm
in.	**49/64**	**25/32**	**51/64**	**13/16**	**53/64**	**27/32**	**55/64**	**7/8**	**57/64**	**29/32**	**59/64**	**15/16**	**61/64**	**31/32**	**63/64**	**1**	**in.**
in	0.7656	0.7812	0.7969	0.8125	0.8281	0.8437	0.8594	0.8750	0.8906	0.9062	0.9219	0.9375	0.9531	0.9687	0.9844	1.000	in
mm	19.447	19.844	20.241	20.637	21.034	21.431	21.828	22.225	22.622	23.019	23.416	23.812	24.209	24.606	25.003	25.400	mm

TABLE 2 — CONVERSION OF LENGTHS, yard-pound system ⇌ metric system

UNIT	inches	feet	yards	rods	furlongs	miles	mm	m	km	UNIT
1 inch	1.000	0.08333	0.02778	—	—	—	25.40	0.0254	—	1 inch
1 foot	12.00	1.000	0.3333	0.06061	—	—	304.8	0.3048	—	1 foot
1 yard	36.00	3.000	1.000	0.1818	—	—	914.4	0.9144	—	1 yard
1 rod	198.0	16.50	5.500	1.000	0.025	0.003125	—	5.029	0.005029	1 rod
1 furlong	—	660.0	220.0	40.00	1.000	0.1250	—	201.2	0.2012	1 furlong
1 mile	63,360	5,280	1,760	320.0	8.000	1.000	—	1,609	1.609	1 mile
1 millimetre	0.03937	0.003281	0.001094	—	—	—	1.000	0.001000	—	1 mm
1 metre	39.37	3.281	1.094	0.1988	—	—	1,000	1.000	0.0010	1 metre
1 kilometre	39,370	3,281	1,094	198.8	4.970	0.6214	—	1,000	1.000	1 km

TABLE 3 — CONVERSION OF AREAS, yard-pound system ⇌ metric system

UNIT	sq in.	sq ft	sq yd	acres	sq miles	hectares	cm^2	m^2	km^2	UNIT
1 sq in	1.000	0.006944	—	—	—	—	6.452	—	—	1 in^2
1 sq ft	144.0	1.000	0.1111	—	—	—	929.0	0.0929	—	1 ft^2
1 sq yd	1,296	9.000	1.000	—	—	—	8361	0.8361	—	1 sq yd
1 acre	—	43,560	4,840	1.000	0.001562	0.4047	—	4047	0.004047	1 acre
1 sq mile	—	—	—	640.0	1.000	259.0	—	—	2.590	1 sq mile
1 hectare	—	—	11,960	2.471	0.003861	1.000	—	10,000	0.01000	1 hm^2
1 sq km	—	—	—	247.1	0.3861	100.0	—	1,000,000	1.000	1 km^2
1 mm^2	0.001550	—	—	—	—	—	0.01000	0.000001	—	1 mm^2
1cm^2	0.1550	0.001076	—	—	—	—	1.000	0.000100	—	1 cm^2
1 dm^2	15.50	0.1076	0.01195	—	—	0.000001	100.0	0.01000	—	1 dm^2
1 m^2	1,550	10.76	1.195	0.0002471	—	0.000100	10,000	1.000	0.000001	1 m^2

TABLE 4 — CONVERSION OF VOLUMES, yard-pound system ⇌ metric system

UNIT	Canadian gallons	U.S. gallons	cubic inches	cubic feet	cu. cm (mL or cm^3)	litres (L or dm^3)	cu. m (m^3)	Mass for water yd-lb	metric	UNIT
1 gallon										1 gallon
Canadian	1.000	1.200	277.4	0.1605	4546	4.546	0.004546	10.00 lb	4.536 kg	Canadian
US	0.8333	1.000	231.2	0.1338	3785	3.785	0.003785	8.333 lb	3.780 kg	US
1 barrel (oil)	35.00	42.00	9,709	5.617	159,000	159.0	0.1590	—	—	1 bbl (oil)
1 in^3	0.003605	0.004325	1.000	0.000579	16.39	0.01639	0.000164	0.036 lb	16.35 g	1 in^3
1 ft^3	6.230	7.474	1,728	1.000	28,320	28.32	0.02832	62.30 lb	28.26 kg	1 ft^3
1 cm^3	0.000220	0.000264	0.06102	0.000035	1.000	0.001000	0.000001	0.0022	0.999 g	1 cm^3
1 L or dm^3	0.2200	0.2640	61.02	0.03531	1,000	1.000	0.001000	2.200 lb	0.999 kg	1 L or dm^3
1m^3	220.0	264.0	61,020	35.31	1,000,000	1,000	1.000	2,200 lb	999.0 kg	1 m^3
1 acre inch	22,610	27,140	—	3,630	—	—	102.8	113.0 tons	102.6 t*	1 acre inch
1 acre foot	271,400	325,600	—	43,560	—	—	1233	1,357 tons	1,231 t*	1 acre foot
1 pint:										1 pint:
Canadian	0.1250	0.1500	34.67	0.02006	568.3	0.5683	—	1.250 lb	0.567 kg	Canadian
US (liquid)	0.1042	0.1250	28.90	0.01672	473.2	0.4732	—	1.042 lb	0.473 kg	US (liq.)
US (dry)	*0.1212*	*0.1455*	33.62	0.1946	550.6	0.5506	—	—	—	US (dry)
1 quart:										1 quart:
Canadian	0.2500	0.3000	69.35	0.04012	1,137	1.137	—	2.500 lb	1.134 kg	Canadian
US (liquid)	0.2083	0.2500	57.80	0.03345	946.4	0.9464	—	2.083 lb	0.945 kg	US (liq.)
US (dry)	*0.2424*	*0.2909*	67.26	0.03892	1,101	1.101	—	—	—	US (dry)
1 tsp	—	—	—	—	5	—	—	—	—	1 tsp
1 tbsp	—	—	—	—	15	—	—	—	—	1 tbsp

Values are given to the fourth significant figure (except for mass)

*t = tonne (1,000 kg)

TABLE 5 — CONVERSION OF CAPACITIES AND FLOW RATES, yard-pound system ⇌ metric system

FLOW RATE	Canadian gpm	U.S. gpm	ft³/sec	m³/s	m³/min.	L/s	L/min.	FLOW RATE
1 Canadian gpm	1.000	1.200	0.002675	0.000076	0.004546	0.07577	4.546	1 Canadian gpm
US gpm	0.833	1.000	0.002229	0.000063	0.003785	0.06309	3.785	1 US gpm
100 Canadian gpm	100.0	120.0	0.2675	0.007577	0.4546	7.577	454.6	100 Canadian gpm
100 US gpm	83.33	100.0	0.2229	0.006309	0.3785	6.309	378.5	100 US gpm
1 ft³/sec	373.8	448.4	1.000	0.02832	1.699	28.32	1699	1 cu. ft/sec
1m³/s	13.200	15,840	35.31	1.000	60.00	1,000	60,000	1 cu. m/sec
1m³/min.	220.0	264.0	0.5885	0.01667	1.000	16.67	1,000	1 cu. m/min.
1 L/s	13.20	15.84	0.03531	0.001000	0.06000	1.000	60.00	1 litre/sec.
100 L/min	22.00	26.40	0.05885	0.001667	0.1000	1.667	100.00	100 Litres/min

Values are given to the fourth significant figure or to the sixth decimal place

TABLE 6 — CONVERSION OF PRESSURES, yard-pound system ⇌ metric system

UNIT	feet head of water	metres head of water	lb/in²	kg/cm²	kPa	in. of mercury	mm of mercury	milli-bar	Standard atmos.	UNIT
1 ft water	1.000	0.3048	0.4331	0.3045	2.986	0.8842	22.39	29.80	0.02947	1 ft H_2O
1 m water	3.281	1.000	1.421	0.09991	9.797	2.901	73.46	97.75	0.09669	1 m H_2O
1 lb/in²	2.309	0.7038	1.000	0.07031	6.895	2.042	[illegible]	68.93	0.06806	1 psi
1 kg/cm²	32.83	10.01	14.22	1.000	98.07	29.04	735.4	980.7	0.9676	1 kg/cm²
1 kPa	0.3349	0.1021	0.1450	0.01020	1.000	0.2962	7.502	10.00	0.009872	1 kPa
1 MPa	334.9	102.1	145.0	10.20	1,000	296.2	7,502	10.000	9.872	1 MPa
1 in. mercury	1.131	0.3447	0.4898	0.03444	3.377	1.000	25.32	33.76	0.03334	1 in. Hg
1 mm mercury	0.04439	0.01353	0.01934	—	0.1333	0.03925	1.000	1.333	—	1 mm Hg
1 millibar	0.03349	0.01021	0.01450	—	0.1000	0.02962	0.7502	1.000	—	1 mbar
1 bar	33.49	10.21	14.50	1.020	100.0	29.62	750.2	1 000	0.9872	1 bar
atmos	33.93	10.34	14.70	1.033	101.3	30.00	760.0	1.013	1.000	1 std atmos

kPa .... kilopascals MPa .... megapascals

Water and inches of mercury at 15.5 deg C (60.0 deg F)

Millimetres of mercury and standard atmosphere at 0 deg C (32 deg F)

WATER REQUIREMENTS AND PUMP CAPACITY

Apart from irrigation and other continuous processes — which usually have their own pumps — the use of water is intermittent but has well-defined peak periods. The time, duration, and frequency of the peak periods vary with each installation, but the bulk of the day's consumption occurs during a total of two to six hours. Thus the pump capacity must relate to the peak requirements rather than to the total daily consumption.

Tables 7 and 8 give typical consumptions and flow rates for everyday uses of water to provide a basis for estimating the total daily consumption and the peak requirements.

A practical and generally accepted rule for sizing the pump is that its capacity in U.S. gallons per minute must not be less than either the number of fixtures installed or the peak demand of the largest single fixture. In metric terms, the pump's capacity in litres per minute must not be less than FOUR TIMES the number of fixtures installed or less than the peak flow rate of the largest single fixture.

EXAMPLE 1. Modern dwelling with 3 bedrooms and 2 bathrooms

List of fixtures			Flow rates per fixture US gpm	L/min.
1	Kitchen sink		5.0	18.0
1	Dishwasher		2.0	7.2
1	Laundry tub		5.0	18.0
	Automatic washing machine		5.0	18.0
	Bathtubs		6.0	21.6
2	Lavatory basins		2.0	7.2
2	Water closets		3.0	10.8
10	**fixtures**	**largest fixture**	**6.0**	**21.6**
PUMP CAPACITY			**10.0**	**40.0**

EXAMPLE 2. Dairy farm with house as Example 1, milking barn with 3 fixtures, livestock and poultry

		Daily consumption US gal.	Litres
50	Milking cows	1 750	7 000
35	Dry cows and heifers	420	1 680
400	Chickens	30	120
TOTAL (pumped in 2 hours)		**2.200**	**8.800**

	Flow rates US gpm	L/min.
Farm house (from Example 1)	10.0	40.0
Milking barn (3 fixtures)	3.0	12.0
Livestock and poultry (daily consumption divided by 120 minutes)	18.3	73.3
PUMP CAPACITY	**31.3**	**125.3**

Another method of sizing the pump for a dwelling house allows for a low-yielding well. It takes into account the yield of the well, the duration of the peak demand, and the storage capacity of the well. In addition, it automatically compensates for different standards of living as it counts not occupants but bedrooms and bathrooms.

The yield of the well can be established by test, and the storage capacity of the well can be estimated from the following. A 6 in. or 150 mm well holds about 1.25 US gal/ft or 15.5 L/m. A 4 in. or 100 mm well holds about 0.50 US gal/ft or 6.2 L/m. The peak demand and its duration can be calculated from the following formulas.

PEAK DEMAND = 100 (No. of bedrooms) US gal
or 400 (No. of bedrooms) litres

DURATION OF PEAK DEMAND

$$= \frac{100\ (\text{No. of bedrooms})\ \text{minutes}}{3\ (\text{No. of bathrooms})}$$

PEAK FLOW RATE

$$= \frac{\text{Peak demand}}{\text{Duration of peak demand}}$$

If the peak flow rate exceeds the yield of the well, the difference must come from the storage in the well.

MAXIMUM FLOW RATE FROM STORAGE

$$= \frac{\text{Storage in well}}{\text{Duration of peak demand}}$$

EXAMPLE 3. Dwelling house with 3 bedrooms and 2 bathrooms, 6 in (150 mm) well with static water level 20 ft or 6 m below the surface, and a yield of 4.0 US gpm or 15 L/min at a maximum pumping water level of 160 ft or 49 m below the surface. Pump is set 170 ft or 52 m below the surface.

	Yd-lb system	**Metric system**
Peak demand	100 (3) = 300 US gal	400 (3) = 1200 L
Duration of peak demand	$\frac{100\ (3)}{3\ (2)}$ = 50 min	$\frac{100\ (3)}{3\ (2)}$ = 50 min
Pump capacity (minimum)	$\frac{300}{50}$ = **6.0 US gpm**	$\frac{1200}{50}$ = **24.0 L/min.**
Pump capacity from yield	4.0 US gpm	15.0 L/min
Minimum pump capacity from storage	2.0 US gpm	9.0 L/min
Storage in well	1.25 (160 — 20) = 175 US gal	15.5 (49 — 6) = 666 L
Maximum pump capacity from storage	$\frac{175}{50}$ = 3.5 US gpm	$\frac{666}{50}$ = 13.3 L/min
Pump capacity (maximum)	4.0 + 3.5 = **7.5 US gpm**	15 + 13.3 = **28.3 L/min.**

The well can provide adequate water for the domestic requirements of the household. Note that neither well nor pump can provide sufficient water for first-aid fire protection. In some cases, it may be possible to increase the storage by deepening the well and setting the pump lower.

TABLE 7 — TYPICAL USES OF WATER

Example	**US gal. per day**	**Litres per day**
Dwelling houses, for all indoor purposes, per person	100	400
Apartment blocks, per person	60	240
Tourist camps, per person	60	240
Hotels and motels, per guest	40/60	160/240
Day schools, per pupil		
With cafeteria, gym, showers	75/100	300/400
with cafeteria only	25	100
without cafeteria	20	80
Institutions, per resident	75/125	300/500
Hospitals, per bed	250/400	1000/1600
Unlicensed restaurants, per patron	7/10	28/40
Licensed restaurants, per patron	9/12	36/48
Swimming pool maintenance per 100 ft² or 10 m²	30	120
Public washrooms, per person	5	20
Laundromats, per load	50	200
Construction workers, per person	50	200
Factory workers, per person	15/35	60/140
Office workers, per person	15	60
LIVESTOCK (per animal)		
Cattle and horses (drinking)	12	48
Milking cows (drinking)	20	80
Milking cows (servicing)	15	60
Hogs (drinking)	4	16
Sheep or goats (drinking)	2	8
POULTRY (per 100 birds)		
Chickens	5/10	20/40
Turkeys	10/18	40/72
Wash down, per 100 ft² or 10 m²	10	40
Lawn and garden sprinkling per 1,000 ft² or 100 m² (1 in. or 25 mm)	600	2600

TABLE 8 — TYPICAL FLOW RATES

Plumbing fixture	**US gpm**	**L/s**	**L/min.**
Lavatory basin, dishwasher	2.0	0.12	7.20
Kitchen sink, laundry tub	5.0	0.30	18.0
Automatic washing machine	5.0	0.30	18.0
Bathtub	6.0	0.36	21.6
Shower head	5.0	0.30	18.0
Ball cock for water closet	3.0	0.18	10.8
Garden hose, 1/2 in	4.0	0.24	14.4
Garden hose, 5/8 in	5.0	0.30	18.0
Garden hose, 3/4 in	6.0	0.36	21.6
Flush valve for water closet	15.0	0.90	54.0
Drinking fountain	0.75	0.05	3.00
Fire hose, 1½ in., ½ in. nozzle	40.0	24.0	144
First-aid fire protection (min.)	10.0	0.60	36.0
PER FIXTURE for sizing pump	1.00	0.06	3.60

PRESSURE REQUIREMENTS

A pump is a machine for lifting water, so that its selection depends on height as well as quantity. Water flows upward through a pipe against gravity only by applying a pressure in proportion to the height it is raised. This is what a pump does, and height and pressure are the same thing where pumping is concerned. The pressure exerted at the base of a column of water, as in a pipe, can be expressed in feet or metres head of water or in pounds per square inch or kilopascals in accordance with Table 6.

There are losses in the piping system due to friction and other causes when water is flowing. These are expressed in terms of head of water lost per 100 feet or metres of pipe (Tables 9 and 10). The losses through valves and fittings are treated as though they occurred in equivalent runs of straight pipe (Tables 11 and 12). The total losses must be added to the static lift to determine the actual pressure required of the pump, as shown in Figures 1 and 2.

The performance of a centrifugal pump is derived from simultaneous test readings of CAPACITY, TOTAL HEAD, POWER INPUT, and other characteristics. Its most complete expression is in the form of curves on a graph (refer to Figure 5, page 11), but it is generally summarized in tabular form for the catalogue.

It is important to realize that any particular capacity is associated with specific values of the total head (or pressure), power input, and other characteristics. This means that an exact capacity can only be obtained by using a throttling device such as a gate valve to reduce the pressure generated by the pump at that capacity to the pressure requirement of the application. More information about the relationship of pump performance to system requirement is given on page 9.

WORK, ENERGY, POWER, and EFFICIENCY

Work and **energy** have the same meaning and are measured in identical or convertible units, but work is usually visible, while energy is often potential (like the heat energy of gasoline). There are always irretrievable losses in • working of any machine that make the useful work it does less than e energy put into driving it. An everyday example is the mechanical work put out by an automobile engine. This is less than the gasoline's heat energy because, among other things, heat is lost to the atmosphere through the exhaust and radiator.

Power is the rate of doing work or releasing energy, and every machine has a power input and a power output. The ratio of the power output to the power input, known as the **efficiency** of the machine, always has a value of less than one. If this ratio is multiplied by one hundred, it becomes a percentage that shows how well the machine does its job.

The basic characteristics of a pump are CAPACITY, TOTAL HEAD and POWER INPUT. These can be measured during a test and simultaneous values of TOTAL HEAD and POWER INPUT plotted against CAPACITY as curves A and B on Figures 14 and 15.

A pump is a machine for lifting water, and its specification is a statement of POWER OUTPUT. For example, a particular submersible deep-well pump has a CAPACITY of 16.0 US gal./min. or 1.00 litre/sec. against a TOTAL HEAD of 545 feet or 166 metres. The capacity represents a mass of water raised in a given time to a height represented by the total head. The power output can be calculated by the following formulas:

Yard-pound system

Power output (water horsepower)

$$= \frac{\text{(capacity in US gpm) (total head in feet)}}{3960}$$

$$= \frac{(16.0)\ (545)}{3960} \doteq 2.20 \text{ hp}$$

$$\text{or } \frac{2.20}{1.34} \doteq 1.63 \text{ kW}$$

M-tric system

er output

$$= \frac{\text{(capacity in L/s) (total head in metres)}}{101.9}$$

$$= \frac{(1.0)\ (166)}{101.9} \doteq 1.63 \text{ kW}$$

Alternative formula

Power output

$$= \frac{\text{(capacity in L/min.) (total head in metres)}}{6116}$$

As the corresponding power inputs from curves B are 3.30 hp and 2.45 kW, the EFFICIENCY of the pump can now be calculated:

$$\text{EFFICIENCY} = \frac{\text{POWER OUTPUT}}{\text{POWER INPUT}}$$

(yard-pound system)

$$= \frac{2.20 \text{ hp}}{3.30 \text{ hp}} \doteq 0.665 \text{ or } 66.5\%$$

(metric system)

$$= \frac{1.63 \text{ kW}}{2.45 \text{ kW}} \doteq 0.665 \text{ or } 66.5\%$$

The efficiency can also be calculated for other points on the characteristic curves and plotted as curves C. It applies to the pump only without reference to the prime mover or any other part of the complete pumping system.

As an electrical machine, the motor has an efficiency curve D, which is shown superimposed on the pump curves. The overall efficiency of the pump and motor together is the product of their individual efficiencies.

Overall efficiency (at 16.0 US gpm or 1.0 L/s)

$$= \text{(Pump efficiency) (Motor efficiency)}$$

$$= (0.665)\ (0.73) \doteq 0.48 \text{ or } 48\%$$

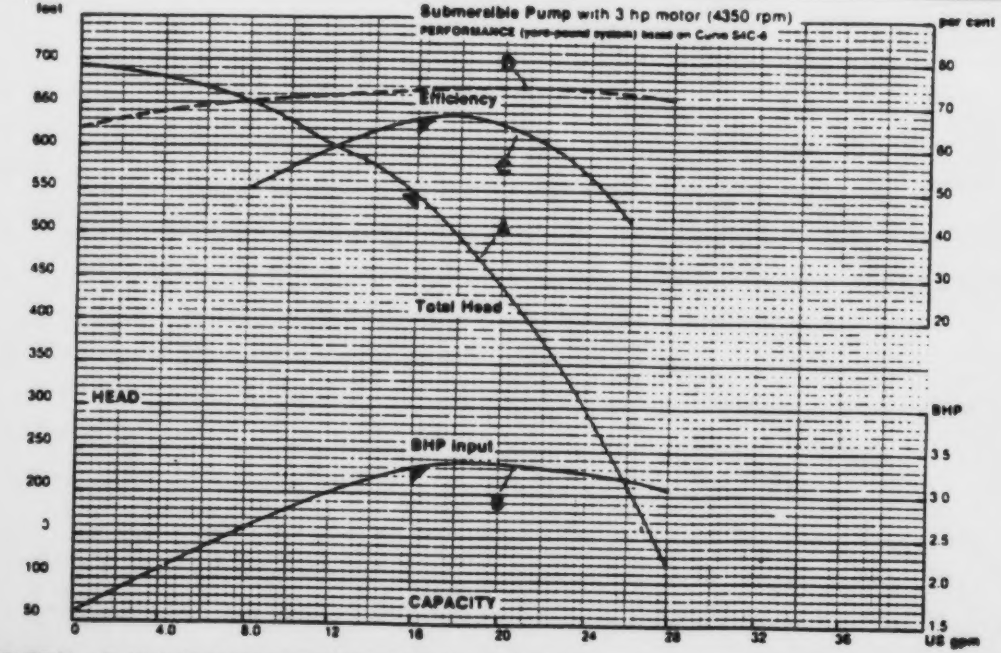
The power input to the motor can be calculated from the speed at which the meter disc revolves when all other equipment is switched off.

$$\text{POWER INPUT TO MOTOR} = \frac{(K)\ (R)\ (3.6)}{t} \text{ kW}$$

where

K = meter constant,
R = number of revolutions counted,
t = time in seconds for R revolutions

For an internal-combustion engine, the power input can be calculated from the rate of fuel consumption.



DUTY POINT:
16.0 US gpm
545 feet
3.3 bhp input
66.5% pump efficiency
48.0% overall efficiency

IGURE 14 — Typical characteristic curves for pump (yard-pound system).

PUMP PERFORMANCE AND SYSTEM REQUIREMENT

The simple procedure of basing the pressure requirement on the estimated maximum capacity of the pump is adequate for most small water systems. For other systems, the pressure requirements can be estimated for a range of capacities and shown as a curve on a graph to the same scales as the pump characteristics. The following example (Figure 3) consists of a 5 hp centrifugal pump discharging water to two locations at different elevations. The suction system is of 4 in. steel pipe, the discharge system is of 3 in. steel pipe. Estimates of the maximum pumping rates are required for three conditions:

1 ..... discharge through branch A only (gate valve in branch B closed)
2 ..... discharge through branch B only (gate valve in branch A closed)
3 ..... discharge through branches A and B (all gate valves open)

The first consideration is the performance of the pump. Figure 4 shows the TOTAL HEAD, POWER INPUT, and EFFICIENCY curves for the 5 hp centrifugal pump. It also shows two curves based on the suction conditions specified in Figure 3 for TOTAL SUCTION LIFT and TOTAL DISCHARGE HEAD. To derive these supplementary curves, it is first necessary to estimate the friction loss in the suction system for several capacities. The TOTAL SUCTION LIFT consists of a static lift of 11.0 feet, an allowance of 1.5 feet for an altitude of 1500 feet, and a friction loss in the suction system that increases with capacity (refer to the following section on SUCTION LIFT for an explanation and example). The difference between the TOTAL HEAD and the TOTAL SUCTION LIFT gives the TOTAL DISCHARGE HEAD.

The next step is to estimate the friction loss and total head requirement for discharge through each branch separately. Figure 3 gives the elevations and equivalent pipe lengths for each branch. Estimate the friction losses at various capacities from Table 9 (or more complete tables in Cameron's Hydraulic Data) and add them to the elevations as follows:

BRANCH A

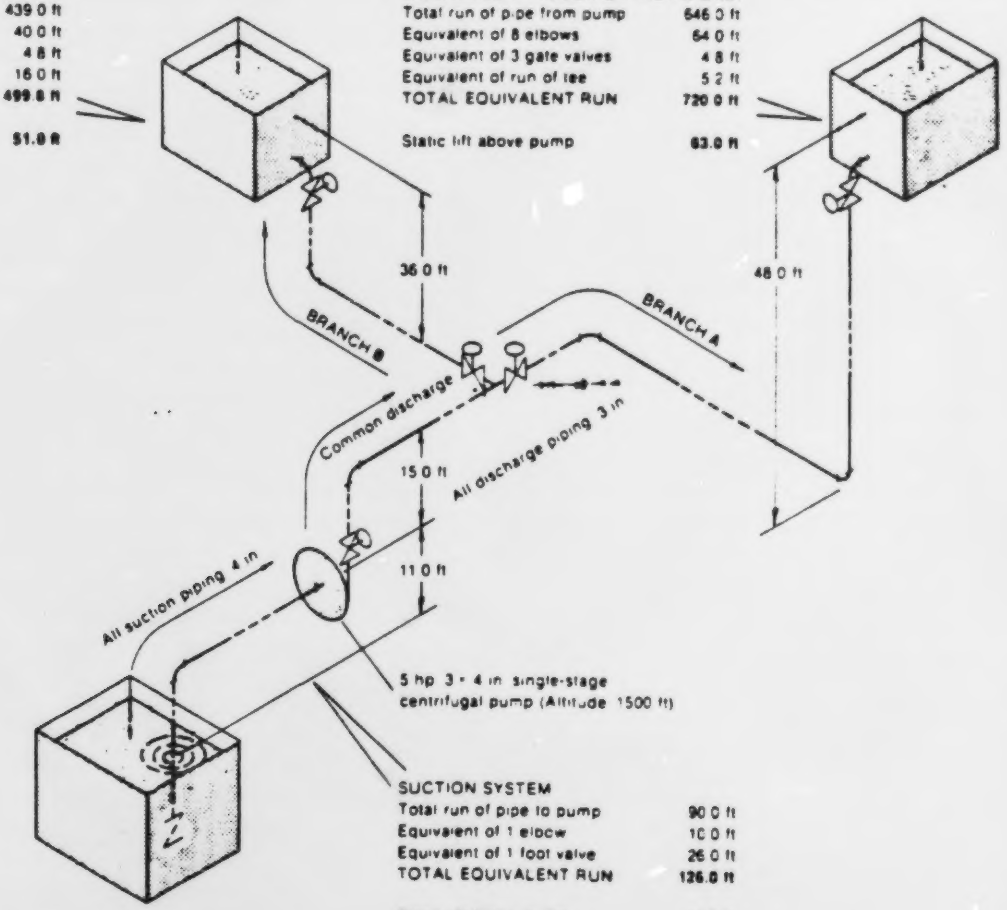
Capacity, US gpm	**0**	**20**	**40**	**60**
Friction loss *ft hd 100 ft pipe*	*0*	*0.23*	*0.82*	*1.74*
ft hd 720 ft pipe	0	1.7	5.9	12.5
Elevation, ft	63.0	63.0	63.0	63.0
Total head, ft	**63.0**	**64.7**	**68.9**	**75.5**

Capacity, US gpm	**80**	**100**	**120**	**140**
Friction loss *ft hd 100 ft pipe*	*2.96*	*4.47*	*6.26*	*8.32*
ft hd/720 ft pipe	21.3	32.2	45.1	59.8
Elevation, ft	63.0	63.0	63.0	63.0
Total head, ft	**84.3**	**95.2**	**108.1**	**122.8**

BRANCH B

Capacity, US gpm	**0**	**20**	**40**	**60**
Friction loss *ft hd/100 ft pipe*	*0*	*0.23*	*0.82*	*1.74*
ft hd 500 ft pipe	0	1.2	4.1	8.7
elevation, ft	51.0	51.0	51.0	51.0
Total head, ft	**51.0**	**51.2**	**55.1**	**59.7**

Capacity, US gpm	**80**	**100**	**120**	**140**
Friction loss *ft hd 100 ft pipe*	*2.96*	*4.47*	*6.26*	*8.32*
ft hd 500 ft pipe	14.8	22.4	31.3	41.6
Elevation, ft	51.0	51.0	51.0	51.0
Total head, ft	**65.8**	**73.4**	**82.3**	**92.6**


36.0 ft
48.0 ft
BRANCH B
BRANCH A
Common discharge
All discharge piping, 3 in.
15.0 ft
11.0 ft
All suction piping, 4 in.
5 hp, 3 × 4 in. single-stage centrifugal pump (Altitude 1500 ft)

DISCHARGE THROUGH BRANCH B ONLY

Total run of pipe from pump	439.0 ft
Equivalent of 5 elbows	40.0 ft
Equivalent of 3 gate valves	4.8 ft
Equivalent to branch of tee	16.0 ft
TOTAL EQUIVALENT RUN	**499.8 ft**
Static lift above pump	**51.0 ft**

DISCHARGE THROUGH BRANCH A ONLY

Total run of pipe from pump	646.0 ft
Equivalent of 8 elbows	64.0 ft
Equivalent of 3 gate valves	4.8 ft
Equivalent of run of tee	5.2 ft
TOTAL EQUIVALENT RUN	720.0 ft
Static lift above pump	**63.0 ft**

SUCTION SYSTEM

Total run of pipe to pump	90.0 ft
Equivalent of 1 elbow	10.0 ft
Equivalent of 1 foot valve	26.0 ft
TOTAL EQUIVALENT RUN	**126.0 ft**
Static lift below pump	**11.0 ft**
Additional lift to compensate for the altitude of 1500 Ft	**1.5 ft**

FIGURE 3 — 5 hp, 3 × 4 in., single-stage, centrifugal pump discharging water to two remote overhead tanks.

SUCTION LIFT

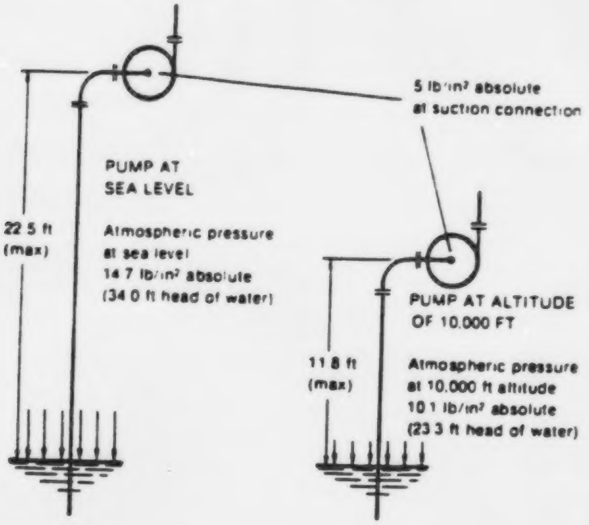
Suction gives a pump the ability to raise or draw water from a source at a lower level. While no one doubts that pressure pushes the water on the discharge side of a pump, the words **raise, draw,** and **suction** make it easy to overlook that atmospheric or other pressure on the source must also push the water on the suction side. Pushing is the only way to move a liquid upwards; it cannot be pulled like a piece of string.

As a result, the height through which a pump can raise water to itself is limited by the difference between the pressure on the source and the minimum pressure that can be developed inside the pump.

The atmospheric pressure decreases as the altitude increases (Table 15) and reduces the maximum practical suction lift by about ONE foot or metre for each 1,000 feet or metres of altitude above sea level.

The pump shown in Figure 6 can reduce the pressure at its suction connection to 5 lb/in² absolute (this is an arbitrary value selected for this example).

FIGURE 6 — Effect of altitude on practical suction lift.



AT SEA LEVEL, the difference in pressure that pushes water into the pump is

(14.7 — 5.0) = 9.7 lb/ins
= (9.7)(2.31)   22.5 ft head of water

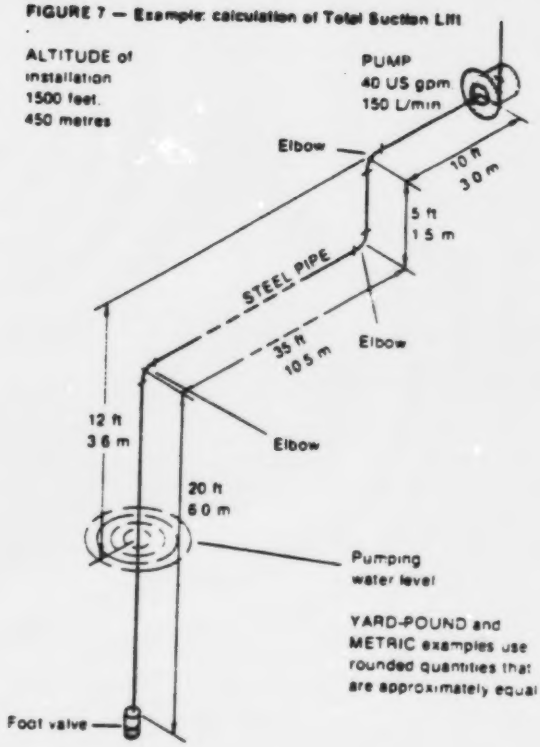
AT 10,000 FT ALTITUDE, the difference in pressure that pushes water into the pump is

(10.1 — 5.0) = 5.1 lb/in²
= (5.1)(2.31)   11.8 ft head of water

This shows a reduction of (22.5 — 11.8) = 10.7 feet in suction lift to compensate for 10,000 feet of altitude, which confirms the rule of thumb of reducing the practical suction lift by 1 foot for each 1,000 feet of altitude.

A reduction in pressure, because of altitude or the conditions inside a pump or other closed vessel, reduces the temperature at which water boils. This limits the degree of low pressure or vacuum that can be developed without releasing vapor bubbles. The relationship between temperature and the vapor pressure at which water boils is shown in Table 16.

FIGURE 7 — Example: calculation of Total Suction Lift



YARD-POUND and METRIC examples use rounded quantities that are approximately equal.

The practical suction lifts and suction heads given in Table 16 are on a comparative basis for various temperatures and altitudes. The basis is a maximum suction lift of 20 feet or 6.0 metres at sea level with cold water at 60 degrees F or 15 degrees C. This means that it is necessary to adjust the values when considering a pump rated at 15 ft suction lift at sea level with cold water. The 5 ft difference in suction lifts is subtracted from suction lifts and added to suction heads, so that +10 ft becomes +5 ft, and —2 ft becomes —7 ft.

The release of vapor bubbles causes discontinuities of flow inside a pump. This is known as cavitation and can do serious damage. The external symptoms of cavitation are loss of pressure, noise, and vibration. The noise is either a rumbling or a rattle as though gravel were in the pump. The internal symptom is the damage by erosion that occurs in the region of higher pressure where the bubbles collapse.

Another factor that affects the suction system of a pump is the solubility of air and gases in water. Air and gases are picked up by rain as it falls to earth. Much more is dissolved by water flowing over and through vegetation and soil. More gases that occur underground, either naturally or by the action of anaerobic bacteria, are absorbed in ground water at pressures above that of the atmosphere. As the amount of air and gas that water can dissolve increases with pressure, a reduction in pressure inside the suction system of a pump may bring about a saturated condition that triggers the release of air and gas bubbles.

TABLE 15 — VARIATION of ATMOSPHERIC PRESSURE with ALTITUDE

ALTITUDE — feet	1,000 below sea l.	0 sea level	2,000	4,000	6,000	8,000	10,000
			above sea level				
ATMOSPHERIC PRESSURE — based on 14.7 lb/in² at sea level							
lb/in²	15.2	14.7	13.7	12.7	11.8	10.9	10.1
feet head, water	35.2	34.0	31.6	29.4	27.3	25.2	23.4
inches, mercury	31.0	30.0	27.8	25.8	24.0	22.2	20.6
kilopascals (kPa)	104.8	101.3	94.5	87.6	81.4	75.2	69.6
metres head, water	10.7	10.34	9.65	8.94	8.31	7.67	7.10
mm, mercury	785	760	709	657	611	564	522

ALTITUDE — metres	250 below sea l.	0 sea level	500	1,000	1,500	2,000	2,500	3,000
			above sea level					
ATMOSPHERIC PRESSURE — based on 101.3 kPa at sea level								
kilopascals (kPa)	104.1	101.3	95.8	90.3	84.8	79.6	74.7	69.9
metres head, water	10.62	10.34	9.78	9.22	8.66	8.12	7.62	7.14
mm, mercury	781	760	718	677	636	597	560	524
lb/in²	15.1	14.7	13.9	13.1	12.3	11.5	10.8	10.1
feet head, water	34.9	34.0	32.1	30.3	28.4	26.7	25.1	23.4
inches, mercury	30.8	30.0	28.4	26.7	25.1	23.5	22.1	20.7

While air and gas bubbles do no damage to the pump, they make priming more difficult, and they may accumulate to interfere with the working of the pump. Note that the escape of flammable gas from a pressure tank or faucet can create a safety problem.

gures 1 and 2 show that friction losses in the pipe lines below ground and on the well side of the pump are expressed as additional depth to water. The following example (Figure 7) shows how to calculate the friction losses in the suction system of a shallow-well pump.

A pump of the capacity shown would probably have a suction connection for 1½ in. (38 mm) pipe. This would be the smallest permissible size of suction pipe, because it is not good practice ot use a pipe smaller than the connection on the pump case. Calculate the TOTAL SUCTION LIFT with 1½ in., 2 in., and 2½ in. suction pipes, and compare the results for the best solution.

EXAMPLE in yard-pound system

Pipe size	**1½ in.**	**2 in.**	**2½ in.**
Vertical runs: (5 + 20) feet	25	25	25
Horizontal runs: (10 + 35) feet	45	45	45
3 — 90 degree elbows (Table 11) equivalent run in feet	12	15	18
Footvalve (as for check valve, Table 11) equiv. run in feet	11	13	16
EQUIVALENT PIPE LENGTH in feet	93	98	104
Friction loss — ft hd/100 ft pipe (Table 9) at 40 US gpm	18.9	5.6	2.36
Estimated friction loss through equivalent pipe length, ft hd	17.6	5.5	2.5
Depth to pumping water level, feet	12.0	12.0	12.0
Allowance for 1500 ft altitude, feet	1.5	1.5	1.5
TOTAL SUCTION LIFT, feet	31.1	19.0	16.0

1½ in. (38 mm) suction pipe would be impractical because the total suction lift would be more than 25 feet or 7.5 metres.

2 in. (50 mm) suction pipe would be a good choice provided the pumping water level remained substantially constant at all seasons.

EXAMPLE in metric system

Pipe size	**1½ in. 38 mm**	**2 in. 50 mm**	**2½ in. 65 mm**
Vertical runs: (1.5 + 6.0) metres	7.5	7.5	7.5
Horizontal runs (3.0 + 10.5) metres	13.5	13.5	13.5
3 — 90 degree elbows (Table 12) equivalent run in metres	3.6	4.5	5.4
Foot valve (as for check valve, Table 12) equiv. run in metres	3.4	4.0	4.9
EQUIVALENT PIPE LINGTH in metres	28.0	29.5	31.3
Friction lose — m hd/100 m pipe (Table 10) at 150 L/min	18.6	5.46	2.32
Estimated friction loss through equivalent pipe length, m hd	5.20	1.60	0.75
Depth to pumping water level, metres	3.60	3.60	3.60
Allowance for 450 m altitude, metres	0.45	0.45	0.45
TOTAL SUCTION LIFT, metres	9.25	5.65	4.80

2½ in (65 mm) suction pipe would be the best choice if the pumping water level is likely to fall to more than 12 feet or 3.6 metres below the pump. It would be necessary to calculate the NPSHA to estimate the lowest practical pumping water level, as follows.

The height through which a pump can raise water to itself depends on the difference between the atmospheric pressure on the source and the pressure inside the suction system. But three factors must be taken into account that reduce the effect of atmospheric pressure.

1 .....The height of the pump above the source, which can be measured.
2 .....The friction losses in the suction system, which can be estimated from Tables 9 through 12.
3 .....The saturation vapor pressure, which can be read from Table 16 according to the temperature of the water.

This information enables the absolute pressure at the impeller entrance to be estimated in terms of the **Net Positive Suction Head Available (NPSHA)** to create flow, as follows.

NPSHA = Ho — Hv — h — hsl
where:
Ho = atmospheric pressure corresponding to altitude (or absolute pressure inside closed vessel, expresses in feet or metres of liquid.
Hv = saturation vapor pressure corresponding to temperature of liquid, expresses in feet or metres of liquid.

TABLE 16 — PRACTICAL SUCTION LIFTS AND HEADS and VAPOR PRESSURES for water

Temperature — deg F	Vapor pressure ft water	ALTITUDE — feet 1,000 below sea l	0 sea level	2,000 above sea level	4,000	6,000	8,000	10,000
		MAXIMUM SUCTION LIFTS based on a maximum of 20 feet at sea level with water at 60 degrees Fahrenheit						
60	0.60	+ 21	+ 20	+ 17½	+ 15½	+ 13½	+ 11½	+ 9½
80	1.15	+ 20½	+ 19½	+ 17	+ 15	+ 13	+ 11	+ 9
100	2.20	+ 19½	+ 18½	+ 16	+ 14	+ 12	+ 10	+ 8
110	2.95	+ 18½	+ 17½	+ 15	+ 13	+ 11	+ 9	+ 7
120	3.90	+ 17½	+ 16½	+ 14	+ 12	+ 10	+ 8	+ 6
130	5.15	+ 16½	+ 15½	+ 13	+ 11	+ 9	+ 7	+ 5
140	6.70	+ 15	+ 14	+ 11½	+ 9½	+ 7½	+ 5½	+ 3½
150	8.55	+ 13	+ 12	+ 9½	+ 7½	+ 5½	+ 3½	+ 1½
160	10.9	+ 10½	+ 9½	+ 7	+ 5	+ 3	+ 1	—1
170	13.8	+ 7½	+ 6½	+ 4	+ 2	+ 0	—2	—4
180	17.3	+ 4	+ 3	+ ½	—1½	—3½	—5½	—7½
190	21.6	0	—1	—3½	—5½	—7½	—9½	—11½
[illegible]	26.6	—5	—6	—8½	—10½	—12½	—14½	—16½
0	32.6	—11	—12	—14½	—16½	—18½	—20½	—22½
212	34.0	—12½	—13½	—16	—18	—20	—22	—24
220	39.7	—18	—19	—21½	—23½	—25½	—27½	—29½
230	47.9	—26½	—27½	—30	—32	—34	—36	—38
240	57.5	—36	—37	—39½	—41½	—43½	—45½	—47½

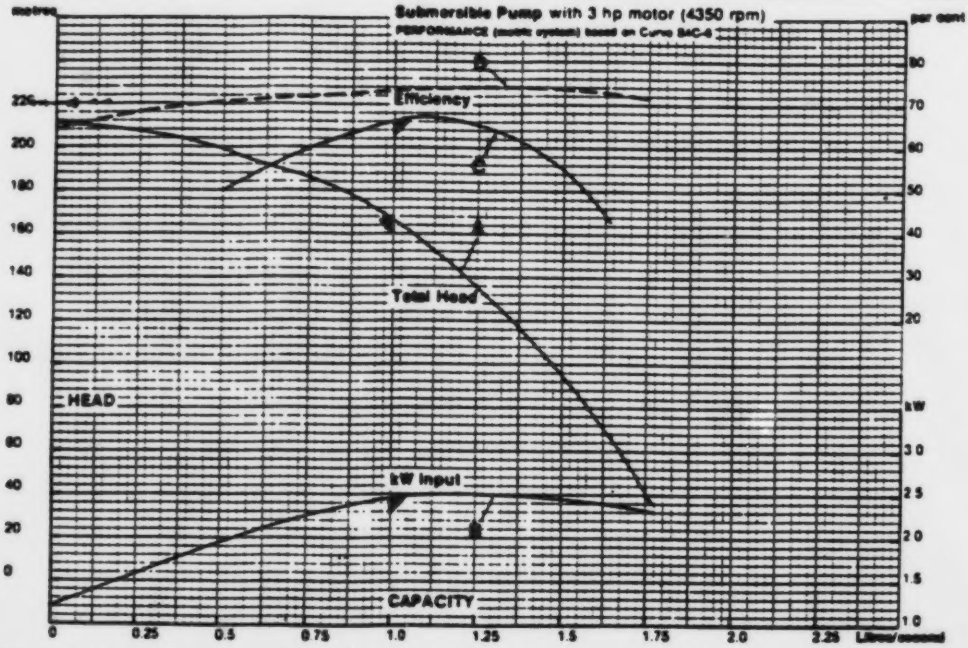
+ ....**SUCTION LIFT** — pump above source

Temperature — deg C	Vapor pressure m water	ALTITUDE — metres 250 below sea l	0 sea level	500 above sea level	1,000	1,500	2,000	2,500	3,000
		MAXIMUM SUCTION LIFTS based on a maximum of 6.0 Metres at sea level with water at 15 degrees Celsius							
15	0.17	+ 6.3	+ 6.0	+ 5.4	+ 4.9	+ 4.3	+ 3.8	+ 3.3	+ 2.8
25	0.32	+ 6.1	+ 5.8	+ 5.2	+ 4.7	+ 4.1	+ 3.6	+ 3.1	+ 2.6
35	0.57	+ 5.9	+ 5.6	+ 5.0	+ 4.5	+ 3.9	+ 3.4	+ 2.9	+ 2.4
45	0.99	+ 5.5	+ 5.2	+ 4.6	+ 4.1	+ 3.5	+ 3.0	+ 2.5	+ 2.0
50	1.27	+ 5.2	+ 4.9	+ 4.3	+ 3.8	+ 3.2	+ 2.7	+ 2.2	+ 1.7
55	1.62	+ 4.9	+ 4.6	+ 4.0	+ 3.5	+ 2.9	+ 2.4	+ 1.9	+ 1.4
60	1.97	+ 4.5	+ 4.2	+ 3.6	+ 3.1	+ 2.5	+ 2.0	+ 1.5	+ 1.0
65	2.57	+ 3.9	+ 3.6	+ 3.0	+ 2.5	+ 1.9	+ 1.4	+ 0.9	+ 0.4
70	3.20	+ 3.3	+ 3.0	+ 2.4	+ 1.9	+ 1.3	+ 0.8	+ 0.3	—0.2
75	3.87	+ 2.5	+ 2.2	+ 1.6	+ 1.1	+ 0.5	0	—0.5	—1.0
80	4.86	+ 1.6	+ 1.3	+ 0.7	+ 0.2	—0.4	—0.9	—1.4	—1.9
85	5.95	+ 0.5	+ 0.2	—0.4	—0.9	—1.9	—2.0	—2.5	—3.0
90	7.15	—0.7	—1.0	—1.6	—2.1	—2.7	—3.2	—3.7	—4.2
95	8.67	—2.2	—2.5	—3.1	—3.6	—4.2	—4.7	—5.2	—5.7
100	10,34	—3.9	—4.2	—4.8	—5.3	—5.9	—6.4	—6.9	—7.4
105	12.4	—5.9	—6.2	—6.8	—7.3	—7.9	—8.4	—8.9	—9.4
110	14.6	—8.1	—8.4	—9.0	—9.5	—10.1	—10.6	11.1	—11.6
115	17.4	—10.9	—11.2	—11.8	—12.3	—12.9	—13.4	—13.9	—14.4

— ....**SUCTION HEAD** — pump below source or pump suction under equivalent pressure

DEVELOPMENT OF FORMULAS FOR POWER		Units in Yard-pound system	Units in Metric (SI) system
MASS is the amount of matter in a body	measured in	pounds (lb)*	kilograms (kg)
DENSITY is the mass per unit volume	measured in	lb/ft³	kg/m³
Practical values of the DENSITY of WATER (15.5 deg C 60 deg F)		62.4	1000
MASS of UNIT VOLUME of WATER			
1.00 U.S. gallon		8.33 lb	
1.00 litre (L)			1.000 kg
ACCELERATION (rate of increase in speed)	measured in	ft/sec²	m/sec²
ACCELERATION DUE TO GRAVITY (comes into play during lifting)		32.2	9.81
FORCE required to move a mass = (MASS) (ACCELERATION)	measured in	poundals*	newtons (N)
FORCE required to support 1.00 US gal. water against gravity		(8.33) (32.2)	
FORCE required to support 1.00 L water against gravity			(1.00) (9.81)
WORK done = (FORCE applied) (DISTANCE moved)	measured in	foot-poundals*	joules (J)
WORK done in lifting 1.00 US gal. water through 1.00 ft		(8.33) (32.2) (1.00)	
WORK done in lifting 1.00 L water through 1.00 m			(1.00) (9.81) (1.00)
POWER = (WORK done)/(Time taken)	measured in	horsepower (hp)	kilowatts (kW)
1.00 hp = (33 000) (32.2) ft-poundals per minute			
POWER to lift 1.00 US gal. water through 1.00 ft in 1.00 minute			
= (8.33) (32.2) (1.00)/(33 000) (32.2) = (8.33)/(33 000) =		$\frac{1}{3960}$	
1.00 kW = 1 000 joules per second			
POWER to lift 1.00 L water through 1.00 m in 1.00 s			
= (1.00) (9.81) (1.00)/(1 000) (1.00) = (9.81)/(1 000) =			$\frac{1}{101.9}$
POWER to lift 1.00 L water through 1.00 m in 1 minute			
= (1.00) (9.81) (1.00)/(1 000) (60) = (9.81)/(60 000) =			$\frac{1}{6116}$

* — The correct units of mass, force and work in the yard-pound system are the **pound, poundal and foot poundal.** The poundal is the force required to accelerate a mass of ONE pound by ONE foot per second (cf. newton), and ONE foot poundal is the work doe when a force of ONE poundal is applied through a distance of ONE foot (cf., joule). The poundal and foot poundal are 32.2 times smaller than the gravitational units of pound (-force) and foot pound (-force), whose use can lead to errors if not understood. There are no gravitational units in the metric (SI) system. The foregoing treatment is consistent for both systems.



DUTY POINT:
1.0 L/s.
166 m.
2.45 kW input.
66.5% pump efficiency.
48.0% overall efficiency

FIGURE 4 — Typical characteristic curves for pump (metric system).

APPENDIX B

VISIT REPORT WITH IT POWER

VISIT REPORT

TO:
IT POWER LIMITED
The Warren Bramshill Rd.,
Eversley Hants, RG27 0PR,
U.K.

Telephone: (0734) 730073
Fax: (0734) 730820

DATE: August 3,4,5, 1988.

PRESENT:
Mr. Anthony Derrick
Miss Sarah Lancashire
D.J. Adkinson

Meetings and discussions were held at the IT Power facilities located about forty minutes from Heathrow airport just south of Reading. Our primary contact was Mr. Anthony Derrick while brief discussions were held with other members of the staff including Sarah Lancashire and Peter Fraenkel regarding our pumping project.

A visit was made on the morning of August 4th to the solar pump testing site operated by Global Renewable Energy Services Limited (GRES) a joint company owned by IT Power and Sir William Halcrow and partners which is located in nearby Swindon.

Initial discussions covered their background work in energy related projects as well as their current work at IT Power which includes two reports of specific interest to our contract. One of these is a report for the Beijer Institute of Sweden which will be presented in draft form at the Solar North Conference in the fall of 1988 and entitled "Solar Photovoltaic Products: A Guide for Development Workers".

The other is a report on water pumping in Pakistan. Additionally a number of publications by their organization were reviewed including:

Solar Water Pumping A Hand Book
The World Bank 1986 Report
Water Pumping Devices by Peter Fraenkel
Test Methods for PV Water Pumping

It appears that all the earlier PV powered water pumping projects have not been outstanding successes with many of the early pumping problems identified in the 1983 World Bank Report being reflected in actual pumping projects in the field. Many of the early systems were put together from off the shelf hardware and were poorly matched components which resulted in poor efficiencies and operations.

Currently the solar water pumping technology reached the degree of technical maturity where in most of the early technical problems have been identified and are now able to be resolved by proper design. These would include such items as submerged pumps being suspended on cables that are too short to accommodate the draw down in the well water levels that occurs after some time of pumping. The current trend in general is towards the acceptance of the AC submerged motor technology and generally away from long shafts which complicate the down hole installation procedure.

The major difficulty with PV water pumping is still identified as a lack of maintenance infrastructure in the developing countries as well as a financial budget to maintain the pumping systems once they have been installed. A notable exception to this is the "Mali Aqua Viva" project which has been most successful due primarily to the concentrated effort to maintain the support organization for the project which currently has close to 100 PV powered water pumps operating in a relatively small section of Mali. It was interesting to note that their projects are currently being financed by a user contribution of up to 25% of the required funds, which is also seen to be a major contributing factor to the successful long term operation of their projects.

This is the basis for one of their major recommendations for any PV pumping project, in that they recommend a concentration of PV pumps with a minimum of 100 units within a relatively accessible area so that a maintenance and personnel organization can be established which is justified by these numbers for maintenance.

It was reported that in Pakistan a number of the diesels used for water pumping are deliberately over-sized by the purchasers. They become a sort of status symbol in the area and the over-size unit capacity is such that the necessary water requirements are pumped in only one or two hours operation per day. Where this occurs, it mitigates against the use of other PV pumps as the owners of these installations tend to sell water to their neighbours at a cost that is minimal and effectively it is cheaper than the cost of a PV pump installation for the neighbour.

Assessing Pumps and Systems

While a price of PV pumping systems varies in a range of $6.00 to $8.00/watt peak of the array from recent quotes received for various systems, caution is advised regarding judging the merits of the systems strictly from a per watt peak basis. It was pointed out that unless the efficiency of the system is considered an under-sized array may be cheaper than an alternative system on a cost per dollars/watt peak basis, but the more expensive system may be more efficient and in fact deliver more water per dollar invested than the cheaper system.

In order to build this factor into the assessment equation, the concept of Specific Capital Cost (SCC) was used in the 1983 World Bank Report to relate the energy delivered to the capital cost of a system. For evaluating two types of solar pumps this is still considered a valid mechanism however, when looking at other types of pumping alternative systems, it is necessary to go to a Life Cycle Costing (LCC) analysis to appropriately assess the alternatives. A trend thus has been away from using the SCC analysis towards a LCC analysis in their work.

Another complicating factor in evaluating systems is the effect of local taxes and tariffs on any imported goods brought into the developing country. To reduce this error potential they have developed a concept of "Border Prices" that do not include taxes or tariffs applied by the local country in order to assess the true economics of the alternative systems.

The general economics of the World Bank reports are still valid with the minor adjustments for the reduced costs of the PV arrays.

When assessing the PV pump against a hand pump concept, the number of bore holes must be allowed for, this is because the number of holes required with PV pumps to deliver a given quantity of water to specific population will be somewhat less than the number of hand pump bore holes required to service the same population.

In considering the sensitivity of PV powered systems efficiency relative to a variation in the head of the water pump, it is seen that the low head systems are particularily vunerable to wide swings in efficiency for relatively minor changes in the heads. This is more or less understandable as the two metre lift when increased to only three metres represents a 50% increase in the design head and these low head systems are particularily subject to changes in efficiency as design head changes.

Considering the value of water pumped, their conclusion has been that either the water has to be pumped or it does not have to be pumped. In these cases where pumping is required, the criteria is not so much as the absolute cost as the relative cost of the various alternative methods of pumping. While a figure of $.06 per cubic metre was quoted in the 1981 report the current Pakistan figures work out to a range of 9.4 cents to 13 cents per cubic metre for diesel and solar pumps respectively.

Applications

The following are the applications which are seen as potentially useful for solar powered water pumps.

- water supply
- garden fountains
- solar DHW circulation
- fish farms - circulation (Malasia & Phillipines)
- water treatment - Nigeria sand filtration treatments
- process water - ice products plant
- desalination

In the short term market the water supply applications for village water and for livestock watering are seen as the major applications. In the water supply end, the trend has been noted towards including the treatment of the water as well as the pumping. The sand filtration method of treatment appears to be preferred over the the UV treatment in as much as the sand filtration method appears to provide a residual resistance to further contamination as opposed to the UV method which reportedly does not.

Australia and the Argentine are seen as countries where cattle watering is now and will become a major market for PV pump applications. Additionally in Pakistan in areas where irrigation by flooding on the Indus Plaines has created a salt build-up over the thirty years of irrigation with high salenity water, "land washing" drainage application is seen where the contaminated soil is actually flooded with clean water and then drained off to remove the salt contamination.

In the long term market, the low head, low lift, small pump set for irrigation is seen as the real large hardware market. Tens of millions of low cost ($300.00) motor pump sets which would be robust portable pumps for irrigation purposes in the far east particularly appear to be feasible when dollar per peak watt systems become a reality.

Sizing Classification

The systems sizing definitions for the 1983 World Bank Report have been modified slightly to include a fourth larger classification for deep well pumping.

These sizes are as follows:

Class	Volume of Water	Depth of Well	Purpose
A	60 metres/day	2 metre	irrigation
B	60 cubic metres/day	7 metre	open dug well - many options
C	20 cubic metres/day	20 metre	village water
D	40 cubic metres/day	40 metre	deep well irrigation

Innovative Pump Types

No particular innovative pump types have been identified other than the Ergo Pump from Canada of which they are aware, and are awaiting some field tests results of this unit.

Grundfos has been promising to develop a larger type unit with a scale of 5 kilowatts as opposed to the present 1500 watts inverter for use with larger system requirements.

Low lift applications using Axial flow type pumps appear to have applications in the high volume low head systems and may have lower costs than the centrifugal type units.

Low power pump units *under a 100 watts seem* to have a number of applications where requirements are not excessive. A French pump manufactured by:

S. International,
25 rue Jean Giraudoux,
75116 Paris
(Tel: 1-720.51.30, Telex:614 836 SINTF)

which was tested a couple of years ago seemed to indicate very good efficiencies and utilize a submerged DC motor.

Pumping Problems

One operational problem has been identified in a few isolated areas that appears to be a reflection of the water quality and material construction. This combination results in a gradual build-up of a coating on the impeller and internal components of the pump and depreciates the performance drastically and is currently considered an electro chemical problem but it necessitates pulling and cleaning the pumps every two or three years. Appears this has happened in Indonesia apparently and in some Japanese systems.

Another technical problem would appear to be failures due to induced voltages from nearby lightning strikes and this has occurred not only in solar pumps but also in diesel operated units in Kenya.

A non technical probelm was identified as the lack of identified jurisdiction or authority for pumping in a given area in many countries. A situation was related where a solar pump installation was planned by one aid group in the Sudan and when the installation team appeared on the site to make the installation, another aid group had just recently installed diesel pump sets making the solar system redundant. Another incident occurred in Mali where one of the IT Power personnel is residing, where a non functioning solar pump set was located within a half a mile of his residence. Despite major efforts he has been unable to identify the party owning the pump or having juridiction over it in order to effect the necessary repairs.

It was mentioned that in Kenya a group known as Kengo was organized by the non government organizations (NGO) to act as a liason between their efforts to eliminate the above mentioned confusion.

Global Visit

A visit was made with Mr. Derrick to the pump testing facility operated by the joint venture GRES which is physically located at the premises of Sir William Halcrow, Consulting Engineer at Swindon. A most informative time was spent inspecting this unique operation and the inventory of pumps accumulated from the World Bank test program described in the 1983 World Bank Report.

The manager of this facility Dr. Bill Gillett was very helpful and informative in describing their facilities and operations. His conclusions after his considerable work in this field is that a high quality pump is the only way to go at this time and that a long term i.e. ten year committment for a PV program is required to set-up the infrastructure and training etc. for a proper aid program.

In addition to pump testing at this site a number of training courses have been operated for technicians from host countries receiving PV pumps. Apparently a common problem with these programs is that frequently workers who have been trained on these courses become in great demand as trained workers once they return to the country and often leave the employ of the host organization.

Discussions were held regarding an appropriate training course for host countries technicians who would be involved in a water pumping project.

Literature Review

In addition to the draft for Solar North, the World Bank Report on The Economic Evaluation and Preliminary Assessment of PV Applications in Pakistan published in March 1988 was reviewed. A review also was made of a number of the pump manufacturers literature from in their library.

A figure of 3,000 PV pumping installations was quoted in a 1987 report and it was estimated that today in 1988 there are over 4,000 active PV pumping systems in existence. Their location is estimated to be as follows:

Australia - 400 systems
India - 500 systems
U.S. - 200 systems
Africa - 2,000 systems
Other - 900 systems
4000 systems

A review was made of the calendar of the upcoming conferences dealing with water and water pumping and the World Exhibition in the U.K. was identified as one of the largest and most appropriate for a PV water pumping applications. This is the World Water '89 Congress in London, U.K., November 14-16, 1989. It was interesting to note in the diary of water related conferences, the number which were either being held in Canada or Canadians were mentioned as organizers. A list of these is attached as Appendix to this report.

Technical Discussion

The following comments were noted during our discussions on technical topics:

Threshold

300 watt operating threshold for solar pumps is realistic today as a maximum level and that 200 watts/metres squared is a good target for operating. This level is much more critical in areas of haze as opposed to clear sky operational conditions.

Standard Day

Their standard day was developed from actual conditions on January 13th at a tropical site described in the 1983 report. There have been no serious discussions or challenges towards changing the standard day as specified.

Cloud Operation

Centrifugal pumps are better for reacting to the movement of clouds across the sun as opposed to reciprocating type pumps.

Lightning

It was suggested that lightning protection be considered on all pumping systems.

Safety

Some concern was expressed for using high voltage systems i.e. 100 volts. Many technicians are now accustomed to working with 12V PV systems and while no incidents are recorded, concern was expressed that complacency may develop when working with 12V systems and caution be disregarded when working on the higher voltage systems.

Emergency Operations

Where village water systems fail, normally manual operation is insufficient to provide sufficient water in any event, and the population reverts to the previous mode of collecting water by hand from other sources to survive until the pump is repaired. One advantage of a 12V operating pump is that it could be operated by batteries should the array and controller fail.

Installation of Systems

A relatively new product "Well Master" is a collapsible reinforced plastic pipe that rolls flat and is seen as a improvement over the rigid plastic conduit previously used for well systems.

Cabling

It is suggested that cables be covered for security and that termite proof cables or armour cable be used in Africa. Reports of mice damage have been received from Australia.

Cable lengths should be reduced as much as possible for minimizing voltage loses.

Crated components should ideally be designed to fit into a "Land Rover Vehicle" for a one trip installation. Crate lengths should be in the area of six foot maximum for this purpose.

Long Term Operational Problems

Maintenance of bearings, brushes, and batteries comprise the major operational problems. Dust build-up on an array is minor, but has to be cleaned occasionally.

Spare parts would ideally be kept on site for minor things such as fuses etc. however experience indicates that spare parts disappear very quickly in Africa. The best method of maintenance suggested is to have a workshop and maintenance facility for such major items as bearings that would look after a minimum of twenty pumps within an area.

Vandalism and theft have not been a big problem except in isolated situations, however theft could be a long term problem as a greater realization of the usefulness of PV modules becomes apparent to the local population. The use of batteries is avoided for this reason as well because the batteries are readily recognized now and tend to disappear.

The falling water tables have caused problems in earlier installations and is suggested that an assumption must be made that water tables will fall and that ten years will bring a change in the water level before the pump life is completed. A change of two metres in the level has been observed over an eight year period in some areas.

General expansion of water use has been observed in Kenya where pumps were installed to help stabilize the Nomads. A doubling of population around the pump sites has been experienced.

The target figures of 40 litres per day per capita is reasonable although people can survive on 5 litres per day. Cattle often use somewhat more than people.

Installation

Installation is usually performed by ex-patriots who are brought to the site for the express purpose of the installation. In some cases the NGO staff has been trained and will do the installation. In the Gambia the Ministry of Water has a trained staff for installation of solar pumps. In Mali the Aqua Viva program have developed a trained staff for installation.

Monitoring Performance

Few sites are monitored in detail or have been examined as closely as the World Bank test pumps in the first phase.

Other institutions working in PV water pumping are Sandia, AFME in France, TUV in Germany who also have a solar pump test facility, ORF in Canada and in Australia a group in Victoria have been doing some testing.

No formal standards were used in their (GRES) evaluation of pump systems as their own criteria were developed for this technology.

R & D Items

The following were suggested as R & D items with potential for PV water pumping systems.

- DC/AC inverter, low cost variable frequency
- Low head design desensitized to head changes
- Mechanism for easy starting of high torque systems (such as self drain hole called leak hole)
- Mono pump diaphram type low friction start
- Motor efficiency
- Pump efficiency
- Water pumping and water treatment combination
- Simplification of maintenance i.e. make repairable product
- Surge protection devices for brushless DC motors
- Lightning protection mechanisms

Note: Manual switching of array configurations has been abandoned due to potential problems and the observation that for a well designed mechanism the cost is equal to a maximum power tracker which would be equally more effective.

DIARY

NEW EVENTS AND DETAIL CHANGES

22-26 May 1988 Bologna, Italy
nternational Symposium on Anaerobic Digestion
nsored by International Association on Water Pollution Research & Control
Conference: Secretariat, 5th International Symposium on Aerobic Digestion, Sogepaco SpA, Piazza della Constituzione 4, 40128 Bologna, Italy.

7-9 June 1988 Vancouver, Canada
Arctic & Marine Oilspill Program (AMOP)
11th annual technical seminar organised by Environment Canada.
Conference: Ms Stephanie Hunt, Technology Transfer & Training Division, Environment, Canada, Ottawa, Ontario K1A 0H3, Canada.

10.23 July 1988 Aberdeen, Scotland
Environmental Impact Assessment
9th international seminar
Conference: Centre for Environmental Management & Planning, Aberdeen University, 48 College Bounds, Old Aberdeen AB9 1FX, Scotland.

18-21 July 1988 Brighton, UK
Confluence 88
14th Biennial IAWPRC Conference and Exhibition on water pollution control; programme covers treatment of effluents, wastewater disposal and reuse of effluents.
Conference: International Association on Water Pollution Research & Control, 1 Queen Anne s Gate, Westminster, London SW1H 9BT, UK.
Exhibition: Howard Phillips, Westrade Fairs Ltd, 28 Church Street, Rickmansworth, Herts WD3 1DD, UK.

19-23 September 1988 Amsterdam, Netherlands
Sewage Sludge Treatment & Use
Co-production of European Water Pollution Control Association and EEC. Organised in conjunction with Aquatech exhibition.
Conference: Industrial Presentations (Europe) BV, Europaplein 8, 1087 GZ Amsterdam, Netherlands.
Ext n: See conference.

9-13 October 1988 Dubai, UAE
5th Arab Water Technology Exhibition & Conference
Conference theme: Corrosion problems in the Middle East.
Conference: Vic French, International Trade Publications Ltd, Queensway House, 2 Queensway, Redhill, Surrey RH1 1QS, UK.
Exhibition: International Conferences & Exhibition Ltd, 29 Dering Street, London W1R 9AA, England.

18-20 October 1988 London, UK
Enprotech '88
2nd national conference & exhibition of environmental protection technology. Conference will cover three themes: Air and noise pollution; water and land pollution; and toxic waste/heavy metal contamination.
Conference: Oxford Conferences Ltd, The Genesis Centre, Science Park South, Birchwood, Warrington WA3 7BH, UK.
Exhibition: Brintex Ltd, 178-202 Great Portland Street, London W1N 6NH, England.

11-13 April 1989 Manchester, England
Immersed Tunnel Techniques
International Conference organised by Institution of Civil Engineers. Includes uses for effluent outfalls and water intakes. Papers invited. 500-word synopses by 1 May 1988.
Conference: Mrs B. O'Donoghue, Conference Office, Institution of Civil Engineers, 1-7 Gt George St, London SW1P 3AA.

17-19 April 1989 Cambridge, England
Pumping: New Challenges — Where Next?
11th British Pump Manufacturers Association technical conference. In association with BHRA and the National Engineering Laboratory. Abstracts of papers required by 27 May 1988.
Conference: Secretary, BPMA, Artillery House, Artillery Row, London SW1P 1RT, England.

24-26 May 1989 Brighton, England
Membrane Separation Processes
International technical conference. Synopses of papers required by 2 May 1988.
Conference: Lorraine Grove, Conference Organiser — Membrane Separation, BHRA, The Fluid Engineering Centre, Cranfield, Bedford MK43 0AJ, UK.

25-26 May 1989 Srinagar, Kashmir, India
Air/Water & Environmental Pollution & Hazardous Wastes
International conference. Titles of papers invited by 15 June 1988.
Conference: Dr VM Bhatnagar, Alena Enterprises of Canada, PO Box 1779, Cornwall, Ontario K6H 5V7, Canada.

8-9 June 1989 Toronto, Canada
9th International Symposium on Environmental Pollution
Titles of proposed papers invited by 15 June 1988.
Conference: DR VM Bhatagnar, Alena Enterprises of Canada, PO Box 1779, Cornwall, Ontario K6H 5V7, Canada.

11-17 October 1989 Beijing, China
ACHEMASIA '89
International meeting on chemical engineering and biotechnology in the Far East. Exhibition and congress.
Conference: DECHEMA, Organisation ACHEMASIA, Postfach 970146, D-6000 Frankfurt am Main 97, West Germany.
Exhibition: See conference

CONFERENCES AND EXHIBITIONS 1987-91

9-13 May 1988 Sevilla, Spain
AH/IAHS Symposium on Hydrology of Wetlands in emi-Arid and Arid Regions
Conference: Prof Dr Pablo Arambarri, Instituto de Recursos Naturales y Agrobiologia, Apartado 1052, 41080 evilla, Spain

16-19 May 1988 Houston, Texas, USA
xth Thematic Conference on Remote Sensing for xploration Geology.
onference: Judith Steeh, PO Box 8618, Ann Arbor, ichigan 48107-8618, USA.

7-20 May 1988 Marseille, France
th Salon Hydroplan
onference: See exhibition.
xhibition: Société Anonyme Foire Internationale de arseille, Parc Chanot BP2, 13266 Marseille Cedex 8, ance.

3-20 May 1988 Wallingford, UK
nternational Conference on River Regime
onference: Ms Jacqueline Poundsford, Conference Organiser, Hydraulics Research, Wallingford, Oxon OX10 8BA, England.

19-20 May 1988 Corfu, Greece
9th European Conference on Environmental Pollution
Conference: Dr VM Bhatnagar, Alena Enterprises of Canada, PO Box 1779, Cornwall, Ontario K6H 5V7, Canada.

19-22 May 1988 Washington DC, USA
1988 Annual International Health Conference
Conference: Conference Department, National Council for International Health, 1101 Connecticut Avenue NW, Suite 605, Washington DC 10036-4390, USA.

22-26 May 1988 Bologna, Italy
5th International Symposium on Anaerobic Digestion
Conference: Secretariat, 5th International Symposium on Aerobic Digestion, Sogepaco SpA, Piazza della Constituzione 4, 40128 Bologna, Italy.

25-27 May 1988 London, England
Condition Monitoring
Conference: Mrs Rosemary Pickford, 2nd Condition Monitoring, BHRA — Fluid Engineering Centre, Cranfield, Bedford MK43 0AJ, UK.

30 May-3 June 1988 Budapest, Hungary
Fluvial Hydraulics
Conference: Fluvial Hydraulics '88 Organising Committee, Vituki, Kvassay Jeno ut 1, H-1095 Budapest, Hungary.

30 May-3 June 1988 Ottawa, Canada
IWRA Congress 1988: Water for World Development: Education and Training
Conference: The Secretariat, Sixth IWRA World Congress on Water Resources, University of Ottawa, 613 King Edward Avenue, Ottawa, Ontario, Canada K1N 6N5

May/June 1988 Srinagar, India
National Conference on Management of Lakes and Inland Water Bodies
Conference: Sri SK Mukerjee, Institution of Public Health Engineers, 1 Garston Place, Calcutta 700001, India.
Exhibition: See conference.

3-8 June 1988 Beijing, China
WaterTech China '88

DIARY

Conference: The Management Committee WaterTech Chi[illegible] Martinik Group, 5/F Fu House, 7 Ice House Stre[illegible]ntral, Hong Kong
Exhi[illegible]: see conference

5-11 June 1988 Toronto, Canada
Symposium on Advances in Reverse Osmosis and Ultrafiltration
Conference: Dr S Sourirajan/Dr T Matsuura, Division of Chemistry, National Research Council of Canada, Ottawa, Ontario, Canada K1A 0R9.

5-11 June 1988 Frankfurt, West Germany
ACHEMA 88 — 22nd Exhibition and Congress
Conference: See exhibition
Exhibition: DECHEMA, Organisation ACHEMA, Postfach 97 01 46, D-6000 Frankfurt am Main 97, West Germany

-8 June 1988 Joensuu, Finland
nternational Symposium on the Hydrology of Wetlands n Temperate and Cold Regions
onference: Ms Leena Rantaarvi, Box 436, SF 00101 elsinki, Finland.

-11 June 1988 Vysoke Tatry, Czechoslovakia
ydrology of Mountainous Areas
onference: Dr L Molnar, Czechoslovak Committee for ydrology, Trnavska 32, 826 51 Bratislava, zechoslovakia.

12 June 1988 Wroclaw, Poland
dvances in Membrane Phenomena and Processes
onference: Dr Alicja Mika, Technical University of roclaw Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, land.

9 June 1988 Orleans, France
H Symposium on the Hydrogeology and Safety of ame D[illegible]ts
onfere[illegible] RGM (J Margat), BP 6009, 45060 Orleans dex, France.

June 1988 Vancouver, Canada
ctic & Marine Oilspill Program (AMOP)
nference: Ms Stephanie Hunt, Technology Transfer & ining Division, Environment Canada, Ottawa, Ontario 0H3, Canada.

June 1988 Toronto, Canada
International Symposium on Environmental ution
ference: Dr VM Bhatnagar, Alena Enterprises of ada, Cornwall, Ontario K6H 5V7, Canada.

4 June 1988 Newfoundland, Canada
d National Conference on Drinking Water
ference: President, Third National Conference on king Water, PO Box 205, St John's, Newfoundland, ada A1C 5J2.

7 June 1988 San Francisco, USA
International Congress on Large Dams
erence: HL Blohm, Secretary, ICOLD '88 Steering mittee, Bechtel Civil Inc, PO Box 3965, San cisco, CA 94119, USA.

June, 1988 Massachusetts, USA
ternational Conference on Computational ods in Water Resources
rence: Massachusetts Institute of Technology, s Lab, Room 48 207, Cambridge, MA 02139, USA.

June 1988 Orlando, Florida, USA
A Annual Conference & Exhibition
l national gathering for water suppliers.
rence: American Water Works Association, 6666 Quinc[illegible]e, Denver, Colorado 80235, USA.
ition: s[illegible]nference.

July 1988 Brisbane, Australia
Quality & Management for Recreation & Tourism
rence: R Sadler, Working Group Secretary, PO Box rth Quay, Brisbane, Queensland, Australia 4000

10-23 July 1988 Aberdeen, Scotland
Environmental Impact Assessment
Conference: Centre for Environmental Management & Planning, Aberdeen University, 48 College Bounds, Old Aberdeen AB9 1FX, Scotland.

11-14 July 1988 Guildford, UK
Risk Assessment of Chemicals in the Environment
Conference: Mr G J Dickens, Chairman — Organising Committee, Avon County Scientific Services, 7 Redcross Street, Old Market, Bristol BS2 0BA, UK.

18-21 July 1988 Brighton, UK
Confluence '88
Conference: International Association on Water Pollution Research & Control, 1 Queen Anne's Gate, Westminster, London SW1H 9BT, UK
Exhibition: Howard Phillips, Westrade Fairs Ltd, 28 Church Street, Rickmansworth, Herts WD3 1DD, UK.

15-19 August 1988 Loughborough, UK
Fourth International Symposium on Regulated Streams
Conference: Dr GE Petts, (FISORS II), Department of Geography, University of Technology, Loughborough, Leicestershire, LE11 3TU, UK.

23-27 August 1988 Sapporo, Japan
9th IAHR International Symposium on Ice
Conference: Hiroshi Saeki, Department of Civil Engineering, Hokkaido University, N-13, W-8, Kita-ku, Sapporo, 060 Japan

23-27 August 1988 Anaheim, California, USA
International Symposium on Artificial Recharge of Groundwater
Conference: Ivan Johnson, Chairman, ISAR Organising Committee, 7474 Upham Court, Arvada, CO 80003, USA.

29 Aug-2 Sept 1988 Delft, The Netherlands
International Symposium on Modelling Soil-Water Structure Interactions
Conference: SOWAS '88, c/o KIvI, PO Box 30424, 2500 GK The Hague, The Netherlands.

4-9 September 1988 Glasgow, Scotland, UK
Internet '88 — From Conception from Completion
Conference: INTERNET 88 (EAL/Tabes) 4th Floor, 43/44 Great Windmill Street, London W1V 7PA, UK.
Exhibition: See conference.

10-14 September 1988 Boston, USA
Distribution System Symposium
American Water Works Association meeting
Conference: American Water Works Association, 6666 West Quincy Avenue, Denver, Colorado 80235, USA.

12-16 September 1988 Rio de Janeiro, Brazil
17th Congress of IWSA
Conference: IWSA, 1 Queen Anne's Gate, London SW1H 9BT, UK.

12-16 September 1988 Wuhan, China
Irrigation Evaluation & Water Management
Conference: Institute of Irrigation Studies, The University, Southampton SO9 5NH, England.

14-16 September 1988 Delft, The Netherlands
Expert Meeting on New Developments in Groundwater Modelling
Conference: International Institute for Hydraulic & Environmental Engineering Oude Delft 95, POB 3015, 2601 DA Delft, The Netherlands.

18-23 September 1988 Rio de Janeiro, Brazil
21st Interamerican Congress and Exhibition on Sanitary and Environmental Engineering
Conference: 21st Congress AIDIS, ABES, Av Beira-Mar 216 — 13 andar, 20 021 Rio de Janeiro RJ, Brazil.
Exhibition: See conference.

18-23 September 1988 Amsterdam, Netherlands
XIIth International Congress for Tropical Medicine & Malaria
Conference: RAI Organisatie Bureau Amsterdam bv Europaplein 12, 1078 GZ Amsterdam, Netherlands

19-21 September 1988 Las Vegas, USA
NWWA National Convention and Exposition
Covers all groundwater topics
Conference: National Water Well Association, 500 W Wilson Bridge Rd, Worthington, Ohio 43085, USA.
Exhibition: See conference

19-23 September 1988 Amsterdam, Netherlands
Sewage Sludge Treatment & Use
Conference: Industrial Presentations (Europe) BV Europaplein 8, 1087 GZ Amsterdam, Netherlands
Exhibition: See conference

19-23 September 1988 Amsterdam, Netherlands
Aquatech '88
Conference: See exhibition
Exhibition: IPE BV, Europaplein 8, 1078 GZ Amsterdam, Netherlands.

21-22 September 1988 Lyon, France
International Conference on Urban Management & Development
Conference: Institut des Sciences et des Techniques de l'Equipement et de l'Environnement pour le developpement (ISTED), 38 rue Liancourt, F75014 Paris France

23-28 September 1988 Beijing, China
IFAT China 1988
Conference: Messe M[illegible]
Messe[illegible] München 12.
[illegible] see conference.

POSTPONED TO 1990

25 Sept-2 Oct 19[illegible] Dubrovnik, Yugoslavia
15th European Regional Conference on Agricultural Water Management.
Conference: Brane Maticic, Biotechnical Faculty, Jamnikarjeva 101, 61000 Ljubljana, Yugoslavia

26-29 September 1988 Venice, Italy
3rd International Conference on Environmental Contamination
Conference: Secretariat, 3rd Environmental Contamination Conference, CEP Consultants Ltd, 26 28 Albany Street, Edinburgh, EH1 3QH, UK.

27-29 September 1988 Eastbourne, England
2nd Annual IWEM Conference & Exhibition
Conference: Bernard Dangerfield, IWEM, 15 John Street London WC1N 2EB, UK.
Exhibition: Brintex Ltd, 178-202 Great Portland Street, London W1N 6NH, England.

4-10 October 1988 Karlsruhe, West Germany
4th Pump Congress
Conference: Fachgemeinschaft Pumpen im VDMA, Postfach 71 08 64, D-6000 Frankfurt/Main 71, West Germany.

6-9 October 1988 Piacenza, Italy
7th Geofluid Biennial International Exhibition
Exhibition: Ente Autonomo Mostre Piacentine, Via Emilia Parmense 17, PO Box 118, 29100 Piacenza, Italy.

9-13 October 1988 Dubai, UAE
5th Arab Water Technology Exhibition & Conference
Conference: Vic French, International Trade Publications Ltd, Queensway House, 2 Queensway, Redhill, Surrey RH1 1QS, UK.
Exhibition: International Conferences & Exhibitions Ltd, 29 Dering Street, London W1R 9AA, England.

11-13 October 1988 London, UK
National Water Exhibition 1988
Exhibition: Turret-Wheatland Ltd, Penn House, Rickmansworth, Hertfordshire WD3 1SN, UK.

11-17 October 1988 Beijing, China
Geology 88
Exhibition: SHK International Services Ltd, 22/F., 151 Gloucester Road, Hong Kong

DIARY

17-19 October 1988   Washington DC, USA
No [illegible] 1
Co[illegible]ce: International Society for Trenchless Technology, 15 John Street, London WC1N 2EB, UK.
Exhibition: Westrade Fairs Ltd, PO Box 53, Rickmansworth, Hertfordshire WD3 2AG, UK.

18-20 October 1988   London, UK
Ozone in Water Quality Management
Conference: Professor R Perry, Public Health & Water Resource Engineering, Department of Civil Engineering, Imperial College, London SW7 2BU.

18-20 October 1988   London, UK
Enprotech '88
Exhibition: Brintex Ltd, 178-202 Great Portland Street, London W1N 6NH, England.

18-29 October 1988   London, UK
Enprotech '88
Conference: Oxford Conferences Ltd, The Genesis Centre, Science Park South, Birchwood, Warrington WA3 7BH, UK.
Exhibition: Brintex Ltd, 178-202 Great Portland Street, London W1N 6NH, England.

19-21 October 1988   Stratford-upon-Avon, UK
Hydrotransport 11 — 11th International Conference on Hydraulic Transport of Solids
Conference: Dorothy Thompson/Lynne Staples, BHRA, Fluid Engineering Centre, Cranfield, Bedford, MK43 0AJ, UK.

20-23 October 1988   Visakhapatnam, India
Association of Hydrologists of India 7th Annual Convention
Conference: Prof VVJ Sarma, Secretary & Treasurer, AHI, Depa[illegible]t of Geophysics, Andhra University, Visak[illegible]am, 530 003

23-28 October 1988   Albury-Wodonga, Australia
Fourth International Micro-Irrigation Congress
Conference: Congress Secretariat, PO Box 29, Parkville, Victoria 3052, Australia.

24-26 October 1988   Pittsburgh, USA
49th International Water Conference
Conference: Engineers Society of Western Pennsylvania, Pittsburgh Engineers Bldg, 337 Fourth Avenue, Pittsburgh PA 15222.

-9 November 1988   Harrogate, UK
Water Modelling & Measurement Conference
Conference: Dorothy Thompson/Lynne Staples, BHRA, Fluid Engineering Centre, Cranfield, Bedford, MK43 0AJ, UK.

-12 November 1988   Ouagadougou, Burkina Faso
Hydrology and Hydrogeology in Arid and Semi-Arid Areas of Africa
Conference: International Water Resources Association, University of Illinois, 208 N Romine, Urbana, IL 61801, USA.

-11 November 1988   Bangkok, Thailand
econd IAWPRC Asian Conference on Water Pollution Control
Conference: Professor Thongchai Panswad, Dept of Environmental Engineering Chulalongkorn University, angkok 10500, Thailand.

-11 November 1988   Bombay, India
Water Pollution & Environmental Control
Conference: Dr VM Bhatnagar, Alena Enterprises of anada, PO Box 1779, Cornwall, Ontario K6H 5V7, anada.

-16 November 1988   St Louis, Missouri, USA
Water Quality Technology Conference
Conference: Rick Harmon, AWWA, 6666 West Quincy venue, Denver, Colorado, 80235 USA.
xhib[illegible] Meetings Department, AWWA: see onference.

16-18 November 1988   Tampa, Florida, USA
Advances in Groundwater Hydrology
Conference: AIH 3416 University Ave SE, Ste 200, Minneapolis, MN 55414, USA.

22-25 November 1988   Lyon, France
Pollutec 88
Conference: See exhibition
Exhibition: Technoexpo, Rue de la Michodiere 8, 75002 Paris, France.

23-24 November 1988   London, UK
Advances in Slow Sand Filtration
Conference: Dr N Graham, Public Health & Water Resource Engineering, Department of Civil Engineering, Imperial College, London SW7 2BU.

28 November-2 December 1988   Hong Kong
Polmet 88: Pollution in the Urban & Metropolitan Environment
Conference: Polmet 88 Secretariat, Hong Kong Institution of Engineers, 9/F, Island Centre, 1 Great George Street, Causeway Bay, Hong Kong.

Early December 1988   Porto Alegre, Brazil
Sediment Budgets
Conference: Local Organising Committee, Symposium on Sediment Budgets, Instituto de Pesquisas Hidraulicas, UFRGS, CP 350, Porto Alegre RS, Brazil.

4-6 April 1989   Nice, France
Technical Advances in Biofilm Reactors
Conference: J Bernard, AGHTM, 9 rue de Phalsbourg, F-75854 Paris Cedex 17, France.

10-14 April 1989   West Berlin
IPW '89
Conference: See exhibition
Exhibition: AMK Berlin, Postfach 19 17 40, Messedamm, D-1000, Berlin 19.

11-12 April 1989   West Berlin
Specialised Conference on The Development of Water Industry Managers.
Conference: IWSA Secretariat, 1 Queen Anne's Gate, London SW1H 9BT, UK.

11-13 April 1989   Manchester, England
Immersed Tunnel Techniques
Conference: Mrs B O'Donoghue, Conference Office, Institution of Civil Engineers, 1 7 Gt George St, London SW1P 3AA, UK.

17-19 April 1989   Cambridge, England
Pumping: New Challenges — Where Next?
Conference: Secretary BPMA, Artillery House, Artillery Row, London SW1P 1RT, England.

11-19 May 1989   Baltimore, Maryland, USA
International Association of Hydrologic Sciences (IAHS) Third Scientific Assembly
Conference: Ivan Johnson, Chairman, ITSA Organising Committee, 7474 Upham Court, Arvada, CO 80003, USA.

18-19 May 1989   Capri, Italy
10th European Conference on Environmental Pollution
Conference: Dr VM Bhatnagar, Alena Enterprises of Canada, PO Box 1779, Cornwall, Ontario K6H 5V7, Canada.

24-26 May 1989   Brighton, England
Membrane Separation Processes
Conference: Lorraine Grove, Conference Organiser — Membrane Separation, BHRA, The Fluid Engineering Centre, Cranfield, Bedford MK43 0AJ, UK.

25-26 May 1989   Srinagar, Kashmir, India
Air/Water & Environmental Pollution & Hazardous Wastes
Conference: Dr VM Bhatnagar, Alena Enterprises of Canada, PO Box 1779, Cornwall, Ontario K6H 5V7, Canada.

8-9 June 1989   Toronto, Canada
9th International Symposium on Environmental Pollution
Conference: Dr VM Bhatnagar, Alena Enterprises of Canada, PO Box 1779, Cornwall, Ontario K6H 5V7 Canada.

18-22 June 1989   Los Angeles, USA
AWWA Annual Conference and Exhibition
Conference: American Water Works Association, 6666 West Quincy Avenue, Denver, CO 80235, USA.
Exhibition: See conference.

21-25 August 1989   Ottawa, Canada
23rd Biennial Congress
Inland waters.
Conference: Dr T'1 Dick, Dept of Environment, Hydraulics Division, CCIW, PO Box 5050, Burlington, Ontario, L7R 4A6, Canada.

28-31 August 1989   Gothenburg, Sweden
International Environmental Exhibition & Congress — Sweden 1989
Conference: See exhibition.
Exhibition: Rolf Lindqvist, Swedish Exhibition Centre, Box 5222, S-402 24 Gothenburg, Sweden.

10-13 September 1989   Glasgow, UK
4th Annual IWEM Conference & Exhibition
Conference: Mrs Lavinia Gittins, IWEM, 15 John Street, London WC1N 2EB, UK.
Exhibition: See conference

11-13 September 1989   Houston, USA
NWWA National Convention
Conference: NWWA, 500 W Wilson Bridge Road, Worthington, Ohio 43085, USA.
Exhibition: See conference.

18-20 September 1989   Manchester, UK
Pumped Storage
Conference: Conference Office, Institution of Civil Engineers, 1 Great George Street, London SW1P 3AA, England.

11-17 October 1989   Beijing, China
ACHEMASIA '89
Conference: DECHEMA, Organization ACHEMASIA, Postfach 970146, D-6000 Frankfurt am Main 97, West Germany
Exhibition: See conference.

14-16 November 1989   London, UK
World Water 89 Congress
Conference: Institution of Civil Engineers, 1 Great George Street, London SW1P 3AA, UK.
Exhibition: Westrade Fairs Ltd, 28 Church Street, Rickmansworth, Hertfordshire WD3 1DD, UK.

February 1990   Abidjan, Cote d'Ivoire
UADE '90
Conference: UADE, 01 BP 1843, Abidjan 01, Cote d'Ivoire.
Exhibition: Westrade Fairs Ltd, 28 Church Street, Rickmansworth, Hertfordshire WD3 1DD, UK.

17-21 June 1990   Cincinnati, Ohio, USA
AWWA Annual Conference and Exhibition
Conference: American Water Works Association, 6666 West Quincy Avenue, Denver, Colorado 80235, USA.
Exhibition: See conference.

24-26 September 1990   Anaheim, California, USA
NWWA National Convention and Exposition
Conference: National Water Well Association, 500 W Wilson Bridge Rd, Worthington, Ohio 43085, USA.
Exhibition: See conference.

21-23 October 1991   Washington DC, USA
NWWA National Convention and Exposition
Conference: National Water Well Association, 500 W Wilson Bridge Rd, Worthington, Ohio 43085, USA.
Exhibition: See conference.

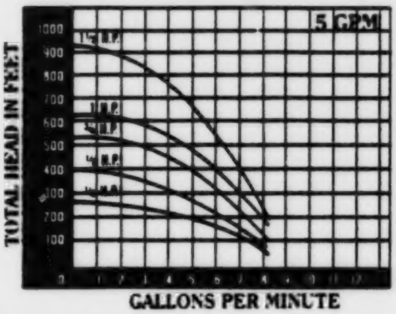
APPENDIX C

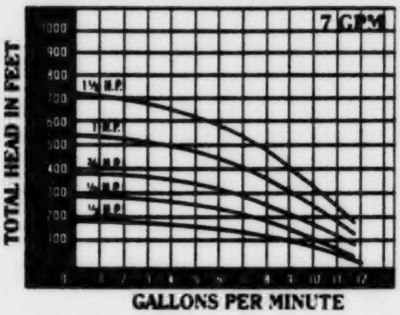
HARDWARE LITERATURE AND INDUSTRY ADDRESSES

- Grundfos Pumps
- Jacuzzi
- A.Y. McDonald

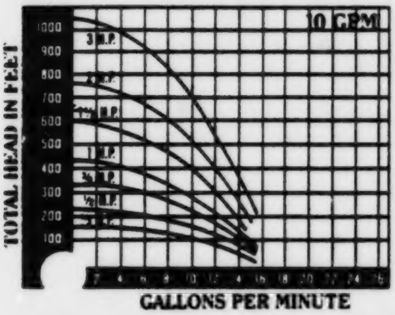
- Industry Addresses

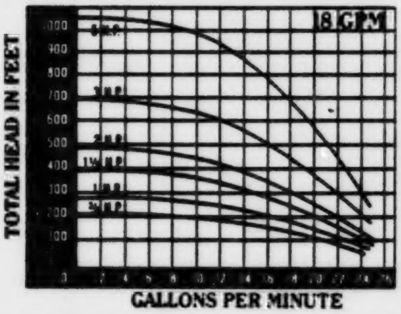
■ THE SOLUTION TO YOUR MOST ABRASIVE PROBLEM.

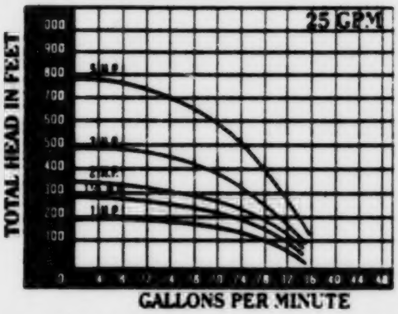




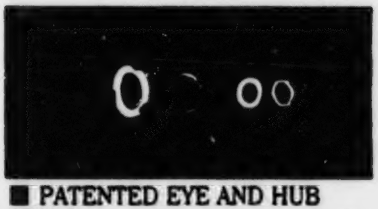
SandHandler™ 4″ Submersibles Performance Charts



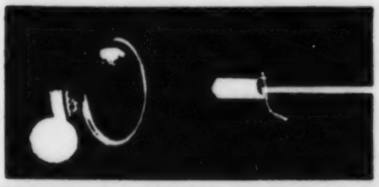




INNOVATION MAKES IT POSSIBLE.



■ **PATENTED EYE AND HUB SEALS.** These seals, placed at the impeller eye and hub in each stage, allow peak efficiencies without abrasive wear. A stainless steel wear ring and thrust washer at the critical points — the eye and hub of the impeller — are part of our unique SandHandler design. These features reduce recirculation and sand locking. And the seals, made of Santoprene,® are highly resistent to sand wear.



■ **CERAMIC SHAFT SLEEVE AND RUBBER BEARING.** The shaft sleeve is encased in a hex-shaped rubber bearing allowing sand to pass through. This reduces bearing wear and keeps the shaft aligned, eliminating premature failure.

■ **BRONZE/STAINLESS STEEL AND THERMOPLASTIC/ STAINLESS STEEL.** The new SandHandler is available in bronze and stainless steel or thermoplastic and stainless steel. You can also select from five performance ranges, 5, 7, 10, 18 and 25 GPM. The Bronze model includes a separate external check valve and the Thermoplastic model includes a built-in check valve.

FINALLY, A WARRANTY TOUGH ENOUGH FOR SAND.

Jacuzzi is so confident in the SandHandler submersible, we back it with our exclusive 2 + 3 Warranty and Extended Replacement Plan, including coverage against the pumping of sand-laden water and sand locking.

JACUZZI STANDARD FEATURES:

- Ceramic shaft sleeve and rubber bearing
- Patented eye and hub seals
- Thermoplastic impellers and diffusers
- Stainless steel shaft, shell and motor coupling
- SandHandler hydraulics for increased efficiencies and fewer stages
- Takes less starting torque
- Available in Bronze/Stainless Steel and Thermoplastic/Stainless Steel in five performance ranges, 5, 7, 10, 18 and 25 GPM

JACUZZI.®
SOLUTIONS THROUGH INNOVATION℠
JACUZZI CANADA
330 Humberline Drive, Rexdale, Ontario M9W 1R5
Factory Branches: Montreal, Winnipeg. PUMPS & WATER SYSTEMS, POOL EQUIPMENT, WHIRLPOOL BATHS & SPAS.

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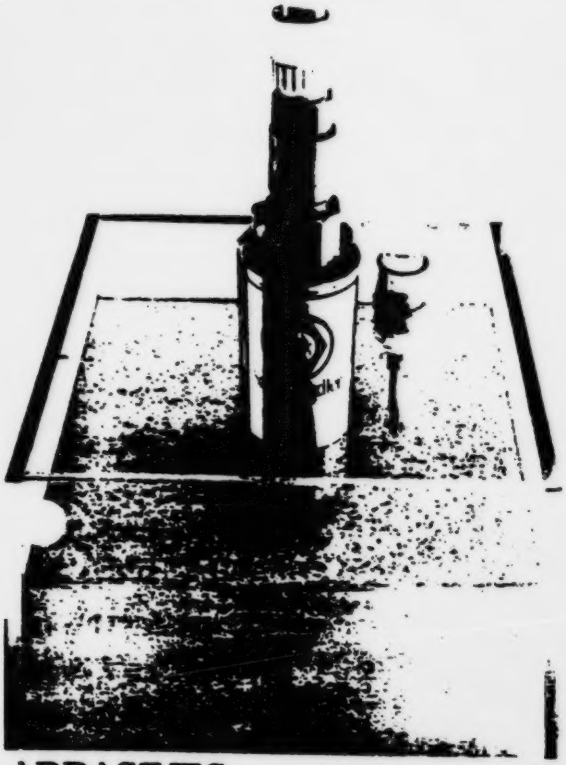
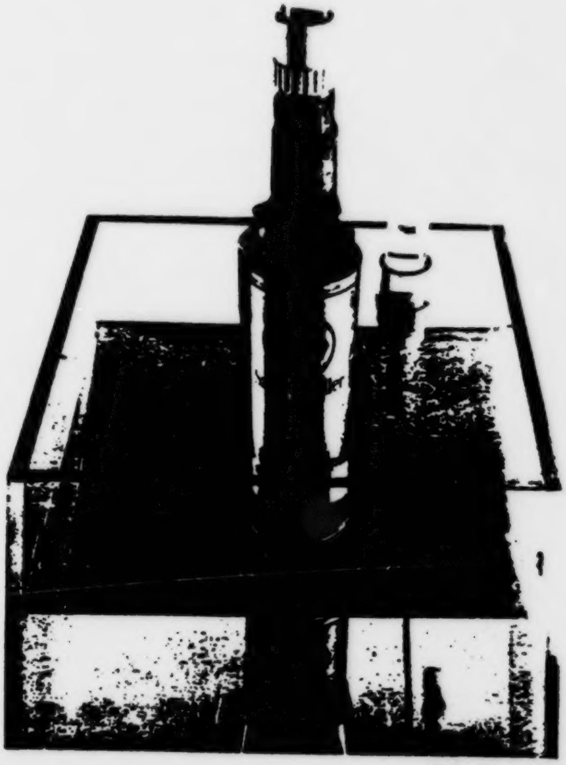
EG 288 — 10

The SandHandler™ by Jacuzzi.



ABRASIVES



CLEAR

CHALLENGE: "Design a pump that handles abrasives or clear water and maintain top efficiencies."

SOLUTION: The SandHandler™ by Jacuzzi.

Customers don't call manufacturers when their pump shuts down — **they call you.** Our new SandHandler™ submersible will reduce your service calls because it handles clear water and sand while maintaining top efficiencies.

The SandHandler™ by Jacuzzi.

SOLAR-POWERED WATER PUMPING SYSTEMS

SOLAR JETS — SOLAR SUBS

ALL CENTRIFUGAL PUMPS

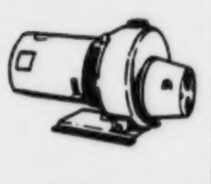
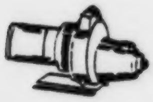
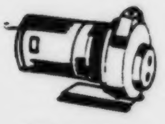
CONDENSED CATALOG AND PRICE LIST

EFFECTIVE APRIL 15, 1987

EST. 1856
McDonald

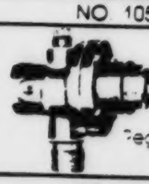
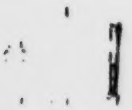
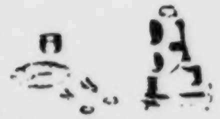
A.Y. McDonald Mfg. Co.
P.O. BOX 508, DUBUQUE, IA 52004-0508
Phone: 319-583-7311
Telex: 43-9020 AYMCD DUQU
Cable: AYMCD DUBUQUE, IOWA U.S.A.

A.Y. McDonald D.C. Pumps and Pump Accessories

PUMPS	DESCRIPTION	MODEL NO.	LIST	WT CUBE
 **1500 SERIES** Convertible/Centrifugal Pump	**1500 BASIC PUMP FOR USE THREE WAYS** **1500DS** without Jet Ejector for 400 to 2100 GPH Lifts water from 16′ to 150′. Water must be within 20′ below the pump. **1500DJ** with Jet Ejector bolted on for higher pressures. Water must be within 25′ below the pump. **1500DD** with Jet Ejector in the well for deeper wells. See Performance in Jet Ejector Section below. Sizes: 250, 500, 700, 900 and 1300 Watts (¼ to 1½ HP DC).	150103DS/ 150203DS (12/24V 300W)	$ 995.00	55# 2.1 Cu Ft
		150204DS (24V 400W)	$1025.00	54# 2.1 Cu Ft
		150305DS (36V 500W)	$ 995.00	53# 2.1 Cu Ft
		150307DS (36V 700W)	$1025.00	54# 2.1 Cu Ft
		150309DS (36V 900W)	$1025.00	54# 2.1 Cu Ft
		150813DS (84V 1300W)	$1950.00	80# 2.1 Cu Ft
 **8100 SERIES**	**8100DJ & 8200DS CENTRIFUGAL PUMPS FOR SHALLOW WELLS ONLY** 810103DJ & 810204DJ with Jet Ejector built in for 75 to 300 gallons per hour at 10 to 25 PSIG and/or 810201DJ for 500 to 3000 gallons per day at 10′ to 50′ lift. Water should be within 15′ below the pump.	810103DJ/ 810203DJ (12/24V 300W)	$550.00	35# 2.1 Cu Ft
		810202DJ (16V 120W)	$550.00	35# 2.1 Cu Ft
 **8200 SERIES**	8200DS without Jet Ejector for 400 to 3000 GPH Lifts water from surface to 100′. Water must be within 20′ below the pump. Sizes: 120, 300, 500, 700, 900 and 1300 Watts (⅙ to 1½ HP DC)	820305DS (36V 500W)	$780.00	41# 2.1 Cu Ft
		820307DS (36V 700W)	$810.00	45# 2.1 Cu Ft
		820309DS (36V 900W)	$810.00	52# 2.1 Cu Ft
		820813DS (84V 1300W)	$1735.00	69# 2.1 Cu Ft

1P ACCESSORIES

SHALLOW WELL	JET EJECTORS SHOWN CONVERT DS PUMPS TO DJ PUMPS		MODEL NO	LIST	WEIGHT
	SP-115/150103 & 150203DS	1500DJ Pumps with bolt-on Jet Ejectors for higher pressures-20 to 85 PSIG Lifts water from 50′ to 200′ Flow from 120 GPH to 800 GPH Water must be within 25′ below the pump See Fig. I back page	150103 & 150203DJ	Add $65.00 to DS Pump	Add 5#
	SP-116/150204DS		150204DJ		
	SP-100/150305DS		150305DJ		
	SP-101/150307DS		150307DJ		
	SP-104/150309DS		150309DJ		
	SP-102/150813DS		150813DJ		

DEEP WELL TWO PIPE	JET EJECTORS SHOWN CONVERT DS PUMPS TO DD PUMPS For Use In 4″ Diameter or Larger Wells		LIST	NO. 105
	SP-115 150103 & 150203DS SP-106 for All Other Pumps except 150813DS - Consult Factory	1500DD Pumps with Jet Ejectors in the well. Pump from 60′ or more below the pump. Lifts to 280′. Flow from 120 GPH to 800 GPH. See Fig. II back page.	Two Pipe Jets - Add $65.00 plus $37.11 for 105 Regulating Valve	 Regulating Valve
SINGLE PIPE	For Use In 2″ or 3″ Diameter Wells			NO. 101
	2″ MP-124/3″ MP-140 for 150103DS & 150203DS 2″ MP-123/3″ MP-139 for All Other Pumps except 150813DS - Consult Factory	1500DD Pumps with Single Pipe Jet Ejectors in the well. Most practical answer for small diameter deeper wells. For convenience, use 101 Casing Adaptor. Add $53.00 for 2″ 101 and $68.80 for 3″ 101 Casing Adaptor. See Fig. III back page	Single Pipe Jets - Add $64.30 for 2″ $90.70 for 3″ plus $37.11 for 105 Regulating Valve	 Casing Adaptor

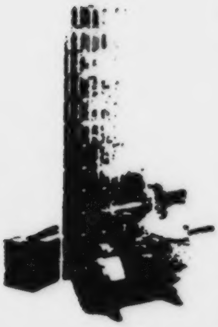
SUBMERSIBLE PUMPS

		MODEL NO.	LIST	WEIGHT
18000 SERIES	**BRUSHLESS DC SUBMERSIBLE PUMP FOR USE IN 4″ DIAMETER OR LARGER WELLS**			
	High-Head Pump — 90 to 300 GPH Lifts to 400+ feet	180825DJ	$3990.00	74# 1.5 Cu Ft
	Medium-Head Pump — 200 to 600 GPH Lifts to 300+ feet	180815DK	$3925.00	68# 1.2 Cu Ft
	Medium-Capacity Pump — 500 to 1400 GPH Lifts to 200+ feet	180810DP	$3925.00	68# 1.2 Cu Ft
	High-Capacity Pump — 1200 to 3000 GPH Lifts to 70+ feet	180809DM	$3925.00	68# 1.2 Cu Ft

See Catalog For Full Item Descriptions

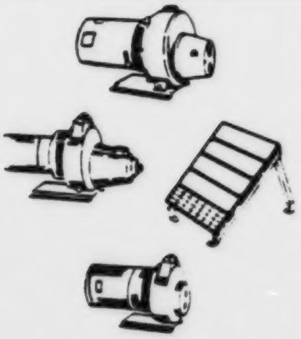
A.Y. McDonald Solar-Recharged Battery and Panel Direct Systems

BATTERY SYSTEMS



	MODEL NO.	LIST	WEIGHT
COMPLETELY AUTOMATIC SOLAR PUMPING SYSTEMS			
A) Includes • McDonald 150103DS 12-Volt DC Pump with Ejector Foot Valve and Pressure Switch for 15 to 30 PSIG On/Off Cycle • 30-Gallon Captive Air Tank with Connecting Fittings Package • 1 - 37 Watt Solar (PV) Panel • Indoor Power Controller - Special H D w/Temp Comp • 1 - 105AH H D Deep-Cycle Battery Add pipe and wiring for average 150 GPD For more water add additional panels	Solar Jet 150103DJII	$2395.00	224# 11.5 Cu Ft
B) 24-Volt Version of "A" with 2 Solar Panels and 2 - 105AH Batteries	150203DJII	$3220.00	294# 13 Cu Ft
PUMPING PACKAGE ONLY			
C) Same as Solar Jet II except • Less Solar (PV) Panels, Batteries and Power Controller	150103DJKL 150203DJKL	$1195.00	111# 9.0 Cu Ft
D) Includes • McDonald 810103DL 12-Volt DC Pump with Foot Valve and Pressure Switch for 15 to 25 PSIG On/Off Cycle • 30-Gallon Captive Air Tank with Connecting Fittings Package • 1 - 37 Watt Solar (PV) Panel • Indoor Power Controller - Special H D w/Temp Comp • 1 - 105AH H D Deep-Cycle Battery Add pipe and wiring for average 120 GPD For more water add additional panels	Solar Jet 810103DS	$1795.00	210# 11.5 Cu Ft
E) 24-Volt Version of "D" with 2 Solar Panels and 2 - 105AH Batteries for 15 to 35 PSIG On Off Cycle	810203DS	$2620.00	180# 13 Cu Ft
PUMPING PACKAGE ONLY			
F) Same as Solar Jet except • Less Solar (PV) Panels, Batteries and Power Controller	810103DSL 810203DSL	$ 795.00	95# 9.0 Cu Ft

PANEL DIRECT SYSTEMS



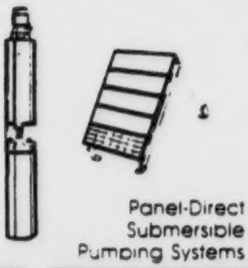
Panel-Direct Surface Mounted Pumping Systems

A Y McDonald has a wide selection of Panel-Direct Systems that operate from sunlight through Photovoltaic Modules with only two wires from the Solar Array to the 1500, 8100 & 8200 Surface-Mounted D C Pumps. See the "Shallow Well Solar Pump Performance" charts for approximate performance with a variety of conditions (gallons per day vs Lift/Head). Then select the pump and quantity of modules required to provide your water needs.

For example If you need 6700 GPD at 33' Lift.

McDonald's Chart Says "Model 150305DS" Pump		$ 965.00
And 8 - 53-Watt Solar Panels (Modules)	@ $690.00 ea	5,520.00
Allow 15% for Racks, Wiring, J-Boxes, etc		828.00
SYSTEM LIST PRICE		$ 7,313.00
LESS APPROPRIATE DISCOUNT		

NOTE Performance of solar systems is relative to weather conditions. Feel free to extrapolate data from McDonald's charts if your applications fall between those shown.



Panel-Direct Submersible Pumping Systems

A Y McDonald also has a wide selection of Panel-Direct Systems similar to the Surface-Mounted Pumps above except in this case, the two wires from the Solar Array are connected directly to the 18,000 Series Submersible D C Pump/Motor in the water. Here refer to McDonald's "Solar Sub" performance chart for GPD and Lift/Head to approximate your application conditions. Select the pump and quantity of Modules closest to your needs.

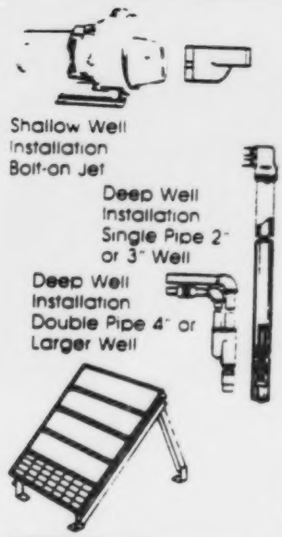
For Example If you need 5500 GPD at 100' Lift.

McDonald's Chart Says "Model 180810DP" Pump		$ 3,925.00
And 16 - 53-Watt Solar Panels	@ $690.00 ea	11,040.00
Allow 15% for Racks, Wiring, J-Boxes, etc		1,656.00
SYSTEM LIST PRICE		$16,621.00
LESS APPROPRIATE DISCOUNT		

YSTE .CCESSORIES AT LIST PRICES

Modules/Panels	6903-223	37-Watt	$545.00	6903-224	47-Watt	$615.00	6903-225	53-Watt	$690.00
uminum Racks	6903-227	4-Panel	$350.00	6903-228	8-Panel	$480.00	6903-226	42-Watt	
2-Volt Battery	6903-162	105 AH	$200.00	6903-207	Array Wiring	$ .24/Ft	Self-Reg	Mod Pr	$550.00
wer Controllers	6903-163	12V Indoor	$350.00	6903-164	24V Indoor	$350.00	6903-115	12V Outdoor	$750.00
nction Boxes	6903-218	Switch	$ 65.00	6903-220	Term Ass'y	$ 50.00	DC Volt/Ammeter		$300.00

PANEL-DIRECT SYSTEMS

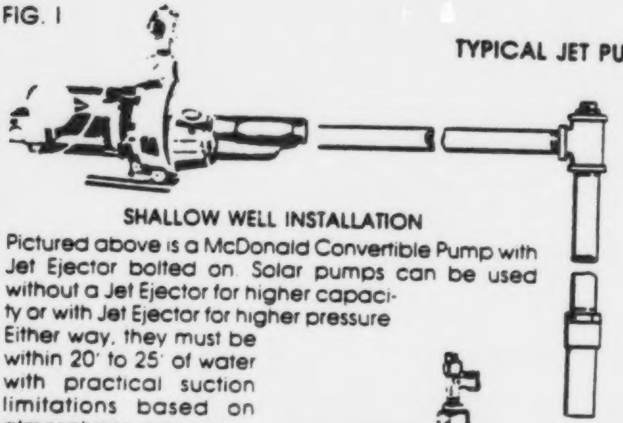


DESCRIPTION	LIST	WT. CUBE
150305DJ-8 — Functional demonstration system for shallow wells, booster systems, etc. to pressurize the water. Includes: • 8 - 47-Watt Solar (PV) Panels • 45° Tilt Mounting Rack with Interconnect Wires • McDonald 150305DS Pump • SP-100 Jet Package and Foot Valve Average 1150 GPD at 16' Suction Lift and 20 PSIG* with Standard Solar Day of 6 KWH/Square Meter	$6750.00	190# 16 Cu. Ft.
150305DD-8 — Deep Well Pumping System for wells 50' below ground level. Same solar array and pump as 150305DJ-8 except use SP-106 Jet Package in well. Average 1500 GPD at 50' to water with Standard Solar Day of 6 KWH/Square Meter	$6750.00	190# 16 Cu. Ft.
150309DD-16 — Deep Well Pumping System to 50' below ground level. Includes: • 16 - 47-Watt Solar (PV) Panels • 45° Tilt Mounting Rack with Interconnect Wires • McDonald 150309DS Pump • SP-106 Jet Package (for installation in well.) Average 2400 GPD at 60' to water with Standard Solar Day of 6 KWH/Square Meter	$12,350.00	330# 30 Cu. Ft.

*PSIG × 2.31 for equivalent feet of head. Gallons to liters × 3.785. Gallons to cubic meters − 264.2. Feet to meters − 3.281.
Request catalog for full line of Solar-Powered Pumps to 1300 Watts or provide application details as follows for sizing assistance from McDonald:
1) Depth to Water 2) Required Gallons Per Day 3) Type and Size of Well 4) Location - including Elevation Above Sea Level

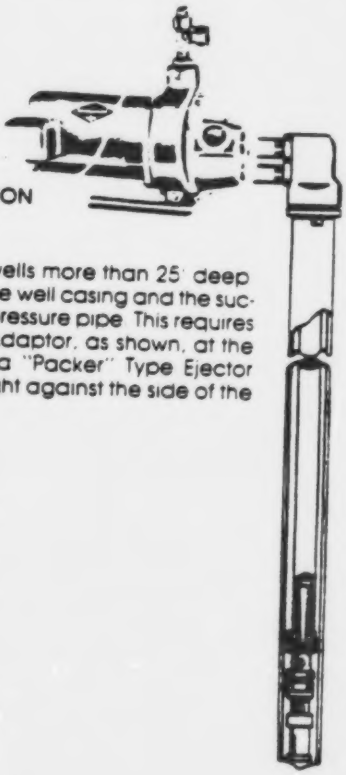
TYPICAL JET PUMP INSTALLATIONS

FIG. I



SHALLOW WELL INSTALLATION

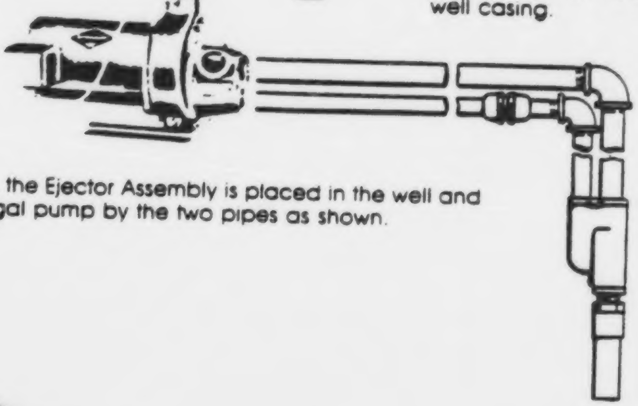
Pictured above is a McDonald Convertible Pump with Jet Ejector bolted on. Solar pumps can be used without a Jet Ejector for higher capacity or with Jet Ejector for higher pressure. Either way, they must be within 20' to 25' of water with practical suction limitations based on atmospheric pressure.



DEEP WELL INSTALLATION SINGLE PIPE 2" OR 3" WELL

For use in 2" and 3" wells more than 25' deep. The space between the well casing and the suction pipe serves as a pressure pipe. This requires the use of a Casing Adaptor, as shown, at the top of the well and a "Packer" Type Ejector Assembly which fits tight against the side of the well casing.

FIG. II



DEEP WELL INSTALLATION DOUBLE PIPE 4" OR LARGER WELL

For deep well application, the Ejector Assembly is placed in the well and connected to the centrifugal pump by the two pipes as shown.

EST. 1856
McDonald

A.Y. McDonald Mfg. Co.

P.O. BOX 508, DUBUQUE, IA 52004-0508 U.S.A.
Phone: 319-583-7311
Telex: 43-9020 AYMCD DUQU
Cable: AYMCD DUBUQUE, IOWA U.S.A.

APPENDIX 2

EUROPE

SUPPLIERS NAMES AND ADDRESSES

AEG
Industriestrasse 29
D-2000 Wedel
Holstein
W GERMANY
Tel: 04103 702-1
Tlx: 2189 520

AL7
Via Don Minzoni 30
400057 Cadilano (BO)
ITALY
Tel: +39 51 766658
Tlx: 511 465 AL73
Fax: +39 51 766165

Automatic Power Ltd   Nav-Aids Only
Parkwood Ind. Estate
Bircholt Rd. Maidstone
Kent   ME15 9XP
UK
Tel: 0622 683756
Tlx: 966680 AUTOPRG

BP Solar Systems Ltd
Aylesbury Vale Ind Park
Farmbrough Close
Stocklake, Aylesbury
Bucks   HP20 1DQ
UK
Tel: 0296 26100
Tlx: 838867 BP SOLE

Chloride Solar Ltd
Lansbury Estate
Lower Guildford Road
Knaphill
Woking   GU21 2EW
UK
Tel: 0483 797773
Tlx: 859791
Fax: 0483 797269

Chroner France
2 Rue du Colonel Driant
75001 Paris
FRANCE
Tel: 1 40 20 7500
Tlx: 230632
Fax: 1 42 61 2120

Chroner Ltd
Sales and Marketing Office
CP House
97-107 Uxbridge Road
London   W5 5TL
UK
Tel: 01 579 6465
Tlx: 264115 CHRNARG
Fax: 01 840 6216

Dulas Engineering
Llwyngwern Quarry
Machynlleth
Powys
SY20 9AZ
UK
Tel: 0654 2782
Tlx: 35851

Dynhelios
2A Du Buisson
76350 Oissel
FRANCE
Tel: 35 64 9747
Tlx: 770 204
Fax: 35 64 0818

Ericsson AB
Power Division
S-16481 Kista
Stockholm
SWEDEN
Tel: 8 7217126
Tlx: 14910
Fax: 8 7217177

Flachglas Solar Technik
Muhlengasse 7
D-5000 Koln 1
GERMANY
Tel: 0221 235191
Tlx: 172214258
Fax: 0221 243811

Fluxinos   Solar Pumps only
58100 Grosseto
Via Genova 8
ITALY
Tel: 0564 451272
Tlx: 500433
Fax: 0564 454237

Grundfos   Solar Pumps only
DK-8850
Bjerringbro
DENMARK
Tel: 6-681 400
Tlx: 60731 GFOS DK
Fax: 6-684472

Helios Technology
Via PO 8
Galliera Vneta 35015
ITALY
Tel: 049 59655655

IBC
P O Box 1107
D-8623 Staffelstein
GERMANY
Tel: 09573 6504
Tlx: 62688

Intersolar Ltd/Solapak Ltd
Factory Three
Cock Lane
High Wycombe
Bucks   HP13 7DE
UK
Tel: 0494 452945
Tlx: 837383

Isofoton S.A.
Oficina Central
cl Miguel Angel, 16
28010 Madrid
SPAIN
Tel: 4012354
Tlx: 49944
Fax: 4105989

Italsolar
Via A. D'Andrea, 6
Nettuno 00048 (RM)
ITALY
Tel: 06-9850246
Tlx: 612441
Fax: 06-9850269

Leroy Somer
Dept of Agriers
Leroy Somer
16014 Angouleme
FRANCE
Tel: 544 3857
Tlx: 205176 F

MBB
Energie und Prozesstechnik
Postfach 801109
D-8000 Munich 80
GERMANY
Tel: 089-46005357
Tlx: 5287117
Fax: 089-46005332

W Mobes Nach. GmbH
Bergiusstrasse 40-44
1000 Berlin 44
W GERMANY
Tel: 030 684 8094
Tlx: 183 432

Electric
Fencing only

Mono Pumps Ltd
Cromwell Trading Est.
Cromwell Road
Bredbury
Stockport SK6 2R
UK
Tel: 061 494 6999
Tlx: 668762
Fax: 061 494 5802

Solar Pumps only

Neste/NAPS
Sahkotie 8
SF-01510
FINLAND
Tel: 358 0 8701611
Tlx: 126048
Fax: 358 0 8701572

Northumbrian Energy
Workshop Ltd
Wind Energy Works
Acomb, Hexham
Northumberland
NE46 4SA
UK
Tel: 0434 606737
Tlx: 537216 WEW

Noack Solar
Kjelsaaveien 160
Box 79, Kjelsaas,
0411 Oslo 4,
NORWAY
Tel: 472 206690
Tlx: 71128 NOACK N

Photolec
Vermont House
District 11
Washington
Tyne and Wear
UK
Tel: 091 4150092
Fax: 091 4150796

Photowatt Intnl S.A.
131 Rt de l'Empereur
92500 Rueil-Malmaison
FRANCE
Tel: 1 47080505
Tlx: 202084

Portsol
Rua Polincarpo, Anjos 62
Lisbon
PORTUGAL
Tel: 4198523
Tlx: 63668

Pumpen Fabrik Wangen GbmH
Ampatal 8
D-8049 Unterbruck
W GERMANY
Tel: 08133 2071
Tlx: 5270504 PULE D

Solar Pumps only

RJM Solar SA
3 Bis ch du Bedex
1226 Thonex
SWITZERLAND
Tel: +41 22 490444
Tlx: 427 130 TXC
Fax: +41 22 [illegible]

R & S Renewable
Energy Systems
PO Box 45
5600 AA Eindhoven
THE NETHERLANDS
Tel: 040 520155
Tlx: 59030 RES NL
Fax: 040 550625

SAB Nife
Box 515
S-261-24
Landskrona
SWEDEN
Tel: 46 418 16280
Tlx: 72416

Satec Ltd
P O Box 12
Weston Road
Crewe CW1 1DE
UK
Tel: 0270 584011
Fax: 0270 589863
Tlx: 36421 SATEC G

Water
Purifiers only

Siemens Solar GmbH
Buchenallee 3
D-5060, Bergisch Gladbach
W GERMANY
Tel: 02204 406-0
Tlx: 884 891 SSOL
Fax: 02204 40666

Sistemi Energetici Integrati
Via S Jacopo,
32-50047 Prato
ITALY
Tel: 0574 24051
Tlx: 570045

Solar Electric Intl.
77 Luqua Ind. Estate
Luqua
MALTA
Tel: 220875
Tlx: 792 ANTENA MW

Solar Energie Technik
Postfach 1180
D/6822 Altlusheim
GERMANY
Tel: 06205 3525
Tlx: 465 849

Solems
3. rue Leon-Blum
Z.I Les Glaises
1120 Palaiseau
FRANCE
Tel: 1 60 133440
Tlx: 604549
Fax: 1 60 133743

Sun Water AB
PO Box 2441
S-45034
Fiskebackskil
SWEDEN
Tel: +46 523 22280
Tlx: 42934
Fax: +416 523 22487

Total Energie
24 Rue Joannes Masse
69009 Lyon
FRANCE
Tel: 78 477272
Tlx: 306 115

Transcoast Ltd
Ave de Gaulle 28
1050 Brussels
BELGIUM
Tel: 32 2 647 7504

Transelektro
1394 Budapest
P O B 377
HUNGARY
Tlx: 224571

AFRICA

Animatics Ltd
PO Box 72011
Nairobi
KENYA
Tel: 331 722
Tlx: 22233

BP Solar Int. Ltd
East Africa Regional Office
PO Box 47796
Nairobi
KENYA
Tel: 254 150 20268
Tlx: 22309 ADJUDICAT

BP Solar
PO Box 31999
Mutaba House
Cairo Road
Lusaka
ZAMBIA
Tel: 26 1 215 390
Tlx: 41180

FNMA
14me Rue Limete
BP 1967
Kinshasa 1
ZAIRE
Tel: 77264/77365
Tlx: 22080

Grundfos Pumps
(Nigeria) Ltd
PO Box 7679
6 Ahman Pategi Road
Kaduna
NIGERIA
Tel: 062 210 881
Tlx: 71363 GFOS NG

Solar Pumps only

Intertec Contracting
(C Africa) Ltd
PO Box 409
Blantyre
MALAWI
Tel: 636825
Tlx: 4544 INTEC MI

Grundfos Agent
Solar Pumps only

Kensid
Abcon House
Sericho Road
PO Box 18511
Nairobi
KENYA -
Tel: 555622
Tlx: 22774

Scan African
Trading Ltd
PO Box 40490
Gabarone
BOTSWANA
Tel: 313638
Tlx: 2638 SCANT BD

Grundfos Agent
Solar Pumps only

SEI Nairobi
PO Box 47384
Nairobi
KENYA
Tel: 335056
Tlx: 22347 PANELAER

INDIA & PAKISTAN

BHEL
PV Division
Vikasnagar
Mysore Road
Bangalore 560026
INDIA

BP Solar Pakistan Ltd
City PO Box 24
33-D Mohammed Ali Society
Karachi 8
PAKISTAN
Tel: 92 21 440432
Tlx: 242620 BPPACK PK

CEL
4 Industrial Area
Sahibabad 201 010
UP
INDIA
Tel: 869157/201071
Tlx: 592203

HMA Investments Ltd
11 West Wharf Road
PO Box 5266
Karachi 2
PAKISTAN
Tel: 202737
Tlx: 25499 HMAI PLC

Grundfos Agent
Solar Pumps only

IMFA
Therubali Dist
Koraput
Orissa 765018
INDIA

REIL
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Bani Park
Jaipur 302006
INDIA
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Tlx: 365403

SE ASIA

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Kuningan Plaza
South Tower
JLHR Rasuna Said
PO Box 2749
Jakarta
INDONESIA
Tel: 62 21 5781520
Tlx: 62679

BP Solar Malaysia
9th Floor
Wisma Damansara
Jalan Semantan
50490 Kuala Lumpur
MALAYSIA
Tel: 60 3 2554322
Tlx: 30742

BP Solar Papua
New Guinea
PO Box 569
Speybank Street
Lae
PAPUA NEW GUINEA
Tel: 675 422200
Tlx: 44141 NE

BP Thai Solar Corp. Ltd
101/47/9 Nava Nakorn's Ind. Est.
Phaholyothin Road. Klong 1
Klong Luang
Pathumethani
THAILAND
Tel: 66 2 529 1105
Tlx: 20889 BPTNSOL TH

Solarex Electric Ltd
18 Floor. Sincere Insurance Bldg
4 Hennessey Road
HONG KONG
Tel: 852 5 285717
Tlx: 780 61254
Fax: 852 5 279704

Solarindo
PT Centronix
Jl Matramen Raya 36
Jakarta
INDONESIA
Tel: 884187
Tlx: 48216

Showa Arco Solar
10 Anson Road 18-24
International Plaza
SINGAPORE 0207
Tel: 2212 433
Tlx: RS 20061 ASIS PR
Fax: 22 58002

JAPAN

Ebara
Asahi Bldg
6-7 Ginza 6-Chome
Chuo-Ku
Tokyo 104
JAPAN
Tel: 572 5611
Tlx: 26976

Solar Pumps only

Hitachi Ltd
6 Kanda-Surugadai
4-Chome
Chiyoda-Ku
Tokyo 101
JAPAN
Tel: 03 258 1111
Tlx: 22395

Hoxan
13-12 Ginza
5 - Chome Chuo-Ku
Tokyo 104
JAPAN
Tel: 3 543 2017
Tlx: 02524470
Fax: 3 546 1637

Komatsu Electronics
2612 Shinomiya
Hiratsuka
Kanagawa
JAPAN
Tel: 0463 231301
Tlx: 47995 KEMS

Kyocera
Chiba-Sakura Plant
4-3 Ohsaku 1-Chome Sakura-Shi
Chiba-Pref. 285
JAPAN
Tel: 0434 981231
Tlx: 03722-181 ACSKR J
Fax: 0434 982215

Mitsubishi Electric
2-3 Marunouchi
2-Cho. Chiyoda-ku
Tokyo 100
JAPAN
Tel: 031 218 3535
Tlx: 24532

Showa Shell
Tokyo Bldg
7-3 Marunouchi 2-Chome
Chiyoda-ku
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Tlx: 22373

AUSTRALASIA

AWA Ltd
47 Forster Road
Walu Bay
Suva
FIJI

BMK
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Fortitude Valley
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AUSTRALIA
Tel: 07 52 7600
Tlx: 1846
Fax: 07 525505

BP Solar Australia
98 Old Pittwater Road
Brookvale
NSW 2100
AUSTRALIA

Grundfos Pumps Pty Ltd Solar Pumps only
PO Box 320
Woodville
S AUSTRALIA 5011
Tel: 8340 0200
Tlx: 88791

Mono Pumps Pty Ltd Solar Pumps only
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Mordialloc
Vic 3195
AUSTRALIA
Tel: (03) 580 5211
Fax: (03) 580 6659

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2A Gatwick Road
Bayswater North
Victoria 3153
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Tel: 03 729 5177
Tlx: 37489
Fax: 03 729 9234

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78 Bibela St. Villawood
PO Box 204
Chester Hill 2163
NWS
AUSTRALIA
Tel: 61-2-727-4455
Tlx: 790-21975
Fax: 61-2-727-7447

Solarwatt
Box 379
Hamilton Central 4007
Queensland
AUSTRALIA
Tel: 617 8541053
Tlx: 41846 AA
Fax: 617 525505

Suntron
2/861 Doncaster Road
Victoria 3109
AUSTRALIA
Tel: 3 848 8944
Tlx: 151224
Fax: 3 848 4873

USA

Arco Solar
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Camarillo
CA 93010
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Tel: 805 388 6335
Tlx: 6716260

Automatic Power Inc.
PO Box 18738
Houston
Texas 77223
USA

Chronar Corp.
PO Box 177
Princeton
NJ 08542
USA
Tel: 609 587 8000
Tlx: 843 394

Currin Corp
P O Box 1191
Midland
MI 48640
USA
Tel: 517 835 7387

Dinh Co
Box 999
Alachua
Florida 32615
USA
Tel: 904 462 3464

ECD/Sovoni[illegible]
1100 W Maple Road
Troy
MI 48084
USA
Tel: 313 362 4170
Tlx: 230648
Fax: 313 362 3120

Intergrated Power Corp
7524 Standish Place
Rockville
Maryland 20855
USA
Tel: 301 294 9133
Tlx: 79 7799
Fax: 301 294 0809

InterSol Power Corp.
11901 W Cedar Avenue
Lakewood
Colorado 80228
USA
Tel: 303 989 8710
Tlx: 45 4592

Jonco Pump Inc Solar Pumps Only
100 Waldron Drive
Durant
Oklahoma 74702
USA

A.Y Macdonald Manufacturing Co
4800 Chavenelle Road
Dubuque
Iowa 52001
USA
Tel: 319 583 7311
Tlx: 43 9020 AYMCE DUQU

Mobil Solar
4 Suburban Park Drive
Billercia
MA 01821
USA
Tel: 617 667 5900

Photocomm Inc
7745 E Redfield Road
Scottsdale
AZ 85260
USA
Tel: 602 948 8003
Tlx: 165095

Photron Inc
77 W. Commercial Street
Willits
CA 95490
USA
Tel: 707 459 3211
Fax: 707 459 2165

Polar Products
2808 Oregon Court. Bldg K-4
Torrance
California 90503
USA
Tel: 213 320 3514
Tlx: 4940451 POLAR LSA

Real Goods
3041 Guideville Road
Ukiah
CA 95482
USA

Solarex Corp
1335 Piccard Drive
Rockville
MD 20850
USA
Tel: 301 948 0202
Tlx: 64358
Fax: 301 948 7148

Speciality Concepts Inc.
9025 Eton Avenue
Suite D
Canoga Park
California 91304
USA
1: 818 998 5238
x: 662914 SCI CMPK UD

Sunfrost
PO Box DD
Arcata
CA 95521
USA
Tel: 707 822 9095

Zome Works Corp
PO Box 25805
Albuquerque
NM 87125
USA
Tel: 505 242 5354

CANADA

Ergo Industries
(Canada) Inc.
201-1777 W. 8th Avenue
Vancouver
British Colombia
V6J 1V8
CANADA
Tel: 604 732 7431
Tlx: 04 54654 VCR

Intersolar Group Canada
415 Brian Court
Pickering
Ontario L1W 3H5
CANADA
Tel: 416 420 1964
Fax: 416 420 6897

SolarPac
1535 Meyerside Drive
Misissanga. L5T IMG
Ontario
CANADA
Tel: 416 674 1616

CENTRAL AND SOUTH AMERICA

Arco Solar LTDA
Praia Do Flamengo 66
Bloco A
22 210 Rio de Janieiro
BRAZIL
Tel: 5521 285 6098
Tlx: 021 30370

BP Solar
Apartado Aereo 59824
Bogota
COLOMBIA
Tel: 57 1 218 3029
Tlx: 45822 BPCO

Enerssin
PO Box 90880
Bogota
COLOMBIA

Grundfos Pumps Corp
Enquiries to:
2555 Clouis Ave
Clouis
California 93612
USA
Tel: 209 292 8000
Tlx: 355 353

Heliodinamica
Caixa Postal 8085
9051 Sao Paulo - SP
BRAZIL
Tel: 011 493 3888
Tlx: 011 71754 HDSP BR
011 71689 HDSP BR

APPENDIX D

PROJECT REPORTS

A. International

- Identified list of projects
    - International Project Reports
- Mali Aqua Viva
- Grundfos Installations

B. Canadian Installations

- List of Identified Projects
    - Project Reports 32201-32223

C. Canadian Overseas Installations

- Project Reports 32401-32409

LIST OF IDENTIFIED PV WATER PUMPING PROJECTS

Dec.1988

national

LOCATION	ARRAY	APPLICATION	RECORD NO.
	720 Wp	village pumping	0
togne,Rochefort	31500 Wp		32001
ti Island,Italy	32500 Wp	RO dessalination	32002
thos,Is.,Greece	10000 Wp	irrigation	32003
a,Island,Italy	31500 Wp	RO dessalination	32004
g, Sanpaloc	224 Wp	school drinking water	32005
lli,Italy	24624 Wp		32006
Manchina,Italy	3000 Wp		32007
l,Portziano,It	750 Wp	water pumping	32008
City, Egypt	3000 Wp	water lifting	32009
Oweinat	3000 Wp	water lifting	32010
Oweinat	18000 Wp	water lifting & dist.	32011
unya	1850 Wp	irrigation pump	32012
hossoun	8300 Wp	desalination	32013
Tension Laborat	7000 Wp	water purification	32014
mrawein	18300 Wp	desalination 2000ppm	32015
,Indonesia	5500 Wp	irrigation	32016
s, Indonesia	25000 Wp	ice making & RO desalin.	32017
Watu Sumba	5760 Wp		32018
a,Sumba,Ind.	3650 Wp	water pumping	32019
uu, Indonesia	3650 Wp		32020
a-Bougandji	1760 Wp	water pumping	32021
soville, Gabon	3200 Wp	water pumping	32022
Senegal	810 Wp	village pump	32023
	720 Wp	village pumping	32024
	720 Wp	village pumping	32025
	1440 Wp	village pumping	32026
ye,Bukina Fosa	1800 Wp	water pumping	32027
sa Egypt	500 Wp	village pumping	32028
sa Egypt	350 Wp	village pumping	32029
sa Egypt	250 Wp	village pumping	32030

Report Number: 32001

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: CEC-DG12053
Array size:31500. Wp
No. of Systems: 2
Telephone:

PROJECT:

Type of Operating Load:
Location: Chevetogne,RochefortInstallation Date: 83/06
Application Classification:

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m Dynamic Head: m

erating Voltage: volts. Module Manufacturer:
otor Type: Motor Manufacturer:
Motor Size:
Pump Type: Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: Array Support Structure:

Available reports:

COMMENTS:

---

is report created as part of the

PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32002

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: CECDG12064
Array size:32500. Wp

Telephone:
No. of Systems: 2

PROJECT:

Type of Operating Load: RO dessalination
Location: Tremiti Island,ItalyInstallation Date: May/84
Application Classification: 11

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m Dynamic Head: m

perating Voltage: volts. Module Manufacturer:
Motor Type: Motor Manufacturer:
Motor Size:
Pump Type: Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: Array Support Structure:

Available reports:

COMMENTS:

---

his report created as part of the

PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32003

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: CEC-DG17 215
Array size:10000. Wp
No. of Systems: 1
Telephone:

PROJECT:

Type of Operating Load: irrigation
Location: Carpathos,Is.,GreeceInstallation Date: April/86
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m Dynamic Head: m

erating Voltage: volts. Module Manufacturer:
otor Type: Motor Manufacturer:
Motor Size:
Pump Type: Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: Array Support Structure:

Available reports:

COMMENTS:

---

s report created as part of the

PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32004

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: CEC/DG17 691
Array size:31500. Wp
No. of Systems: 2
Telephone:

PROJECT:

Type of Operating Load: RO dessalination
Location: Linosa,Island,Italy Installation Date: 1987
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m Dynamic Head: m

erating Voltage: volts. Module Manufacturer:
otor Type: Motor Manufacturer:
Motor Size:
Pump Type: Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: Array Support Structure:

Available reports:

COMMENTS:

---

his report created as part of the

PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

```
                                          Report Number:  32005

               ****   PV WATER PUMPING PROJECT REPORT  ****


 GENERAL:

     Owner: Phillipine Nat.Oil Co.(PNOC-ERDC)  Array size:  224. Wp
         Phillipine-German Solar
         Energy Project,P.O.10083 QuezonCity  No. of Systems:      1
         Telephone: (maine)1103Phil


 PROJECT:

     Type of Operating Load: school drinking water
     Location: Pulong, Sanpaloc    Installation Date: 1983?
     Application Classification: 11.0

             ********************************************

 SYSTEM DESCRIPTION:

 Design Volume:
 Static Head:              m  Dynamic Head:          m

   erating Voltage:     volts.  Module Manufacturer:
 motor Type:                     Motor Manufacturer:
          Motor Size:
 Pump Type: jack pump mfg.local Pump Manufacturer:

 Control Type:                      Control Manufacturer:
 Battery:             Array Support Structure:


     Available reports: Phillipine-German Sol.Energy Proj.-Pamphlet

 COMMENTS:



------------------------------------------------------------------

is report created as part of the

     PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

              by ADKINSON and ASSOCIATES
------------------------------------------------------------------
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Report Number: 32006

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Verona Municipality

Array size:24624. Wp

No. of Systems: 3

Telephone:

PROJECT:

Type of Operating Load:
Location: Zambelli,Italy Installation Date: 1985?
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 60-200m cu/day
Static Head: 350 m m Dynamic Head: 35 bar m

erating Voltage: volts. Module Manufacturer: Pragma 57watt
Motor Type: 2 Tibb asynchronous Motor Manufacturer:
Motor Size: 35 HP
Pump Type: piston type x 2 Pump Manufacturer: Worthington

Control Type: variable frequency Control Manufacturer: Silectron
Battery: 200V 600AH Array Support Structure: ground amount

Available reports: ENEA PV Solar Plant Publication

COMMENTS:
Largest village water pumping installation

----

his report created as part of the

PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32007

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: ISMA Exper.Inst.Agric.MechanizationArray size: 3000. Wp

No. of Systems: 1

Telephone:

PROJECT:

Type of Operating Load:
Location: Tor, Manchina,Italy Installation Date: 1986?
Application Classification:

****

SYSTEM DESCRIPTION:

Design Volume: 200 litre/min.
Static Head: 10m m Dynamic Head: m

perating Voltage: volts. Module Manufacturer: Ansaldo
Motor Type: 3 phase AC Motor Manufacturer:
Motor Size: 1.5kw
Pump Type: submerged Pump Manufacturer:

Control Type: DC/AC 3 phase invert Control Manufacturer:
Battery: 6kW Array Support Structure:

Available reports: ENEA brochure - PV Solar Plants

COMMENTS:

---

his report created as part of the

PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32008

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: ENEA
Array size: 750. Wp
No. of Systems: 1
Telephone:

PROJECT:

Type of Operating Load: water pumping
Location: Castel,Portziano,It Installation Date: 1987
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 30 litres/min.
Static Head: 35m m Dynamic Head: m

erating Voltage: volts. Module Manufacturer: Helios
Motor Type: Motor Manufacturer:
Motor Size:
Pump Type: Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: Array Support Structure:

Available reports: ENEA pamphlet, PV Solar Plants

COMMENTS:

---

his report created as part of the

PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32009

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Egypt
Array size: 3000. Wp
No. of Systems: 1
Telephone:

PROJECT:

Type of Operating Load: water lifting
Location: Sadat City, Egypt
Installation Date: 1981
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m
Dynamic Head: m

erating Voltage: volts.
Module Manufacturer: Arco
Motor Type:
Motor Manufacturer: Grundfos Pumps
Motor Size:
Pump Type: submerged centrif.
Pump Manufacturer: Grundfos

Control Type:
Control Manufacturer:
Battery:
Array Support Structure:

Available reports:

COMMENTS:
proj.run by American University in Cairo

---

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by ADKINSON and ASSOCIATES

Report Number: 32013

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Egypt
Array size: 8300. Wp

Telephone:
No. of Systems: 1

PROJECT:

Type of Operating Load: desalination
Location: Abu Ghossoun
Installation Date: ?
Application Classification:

* * *

SYSTEM DESCRIPTION:

Design Volume: 10 cu.m/day
Static Head: m
Dynamic Head: m

erating Voltage: volts.
Module Manufacturer: AEG
otor Type:
Motor Manufacturer:
Motor Size:
Pump Type:
Pump Manufacturer:

Control Type:
Control Manufacturer:
Battery: 65 amp hr
Array Support Structure:

Available reports:

COMMENTS:
16 kw generator for background

---

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by ADKINSON and ASSOCIATES

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                                        Report Number:  32015

              ****   PV WATER PUMPING PROJECT REPORT  ****


  GENERAL:

      Owner: Egypt                             Array size:18300. Wp

                                               No. of Systems:     1
          Telephone:


  PROJECT:

      Type of Operating Load: desalination 2000ppm
      Location: El-Hamrawein         Installation Date: 1986
      Application Classification: 11.0

              ********************************************

  SYSTEM DESCRIPTION:

  Design Volume: 50m cu/day 250ppm
  Static Head:              m  Dynamic Head:          m

    erating Voltage:     volts.  Module Manufacturer: Photowatt
  motor Type:                     Motor Manufacturer:
           Motor Size:
  Pump Type:                     Pump Manufacturer:

  Control Type:                      Control Manufacturer:
  Battery: 200 amp hr Array Support Structure:


      Available reports:


  COMMENTS:
      reverse osmosis- originally thermal desalination



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              by ADKINSON and ASSOCIATES
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Report Number: 32016

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: BPPT-Badan PengkajianDanPenerapan
BPPT, 14th Floor,
Jalan M.H. Thamrin 8, Jakarta,
Telephone: Indonesia

Array size: 5500. Wp
No. of Systems: 1

PROJECT:

Type of Operating Load: irrigation
Location: Picon,Indonesia
Installation Date: 1983
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 870 m cu./hr.
Static Head: 8-12 m m
Dynamic Head: m

erating Voltage: volts.
Module Manufacturer:
Motor Type:
Motor Manufacturer:
Motor Size:
Pump Type:
Pump Manufacturer:

Control Type: DC/AC variable freq.
Control Manufacturer: Solarverter
Battery: 420 amp hr
Array Support Structure:

Available reports: Solar Village Indonesia phamphlet

COMMENTS:

originally DC/AC normal inverter with battery sys.

---

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by ADKINSON and ASSOCIATES

Report Number: 32017

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: BPPT Badan Pengkajian Dan PenerapanArray size:25000. Wp
BPPT, 14th Floor
Jalan M.H. Thamrin 8 Jakarta No. of Systems: 1
Telephone: Indonesia

PROJECT:

Type of Operating Load: ice making & RO desalin.
Location: Cituis, Indonesia Installation Date: 1982
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 5m cu/day
Static Head: m Dynamic Head: m

perating Voltage: volts. Module Manufacturer:
Motor Type: Motor Manufacturer:
Motor Size:
Pump Type: Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: Array Support Structure:

Available reports: Solar Village Indonesia

COMMENTS:
ice making plant and RO desalination

---

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PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32018

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: BPPT Badan Pengkajian Dan PenerapanArray size: 5760. Wp
BPPT 14th Floor,
Jalan M.H. Thamrin 8, Jakarta No. of Systems: 0
Telephone: Indonesia

PROJECT:

Type of Operating Load:
Location: Gollu Watu Sumba Installation Date: 1982
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: 28 metres m Dynamic Head: m

erating Voltage: volts. Module Manufacturer:
otor Type: Motor Manufacturer:
Motor Size:
Pump Type: DC Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: Array Support Structure:

Available reports:

COMMENTS:
drinking water for 6000 peopl all year

---

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PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32019

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: BPPT Badan Pengkajian Dan PenerapanArray size: 3650. Wp
BPPT, 14th Floor,
Jalan M.H. Tamrin 8 Jakarta No. of Systems: 1
Telephone: Indonesia

PROJECT:

Type of Operating Load: water pumping
Location: Pemuda,Sumba,Ind. Installation Date: 1982
Application Classification:

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: 60 metres m Dynamic Head: m

erating Voltage: volts. Module Manufacturer:
motor Type: AC motor Motor Manufacturer:
Motor Size:
Pump Type: Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: Array Support Structure:

Available reports: Solar Village Indonesia

COMMENTS:
2000 people during the dry season

---

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PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32020

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: BPPT Badan Pengkajian Dan PenerapanArray size: 3650. Wp
BPPT, 14th Floor,
Jalan M.H. Thamrin 8 Jakarta No. of Systems: 1
Telephone: Indonesia

PROJECT:

Type of Operating Load:
Location: Wee Muu, Indonesia Installation Date: 1982
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: 37 metres m Dynamic Head: m

erating Voltage: volts. Module Manufacturer:
otor Type: AC Motor Manufacturer:
Motor Size:
Pump Type: Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: Array Support Structure:

Available reports: Solar Village Indonesia

COMMENTS:

design for 2000 people throughout the year

---

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by ADKINSON and ASSOCIATES

Report Number: 32021

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Gibon

Array size: 1760. Wp

No. of Systems: 1

Telephone:

PROJECT:

Type of Operating Load: water pumping
Location: Onguia-Bougandji Installation Date: 1985
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m Dynamic Head: m

perating Voltage: volts. Module Manufacturer: Solavolt
Motor Type: DC Jacuzzi Motor Manufacturer:
Motor Size:
Pump Type: submerged Pump Manufacturer: Jacuzzi

Control Type: Control Manufacturer:
Battery: Array Support Structure:

Available reports: Complete report by Solavolt

COMMENTS:
Jacuzzi motor burnt out and replaced

---

is report created as part of the

PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32022

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Gabon

Array size: 3200. Wp

Telephone:

No. of Systems: 0

PROJECT:

Type of Operating Load: water pumping
Location: Bolossoville, Gabon Installation Date:
Application Classification:

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m Dynamic Head: m

perating Voltage: volts. Module Manufacturer:
otor Type: Motor Manufacturer:
Motor Size:
Pump Type: submerged centrif. Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: Array Support Structure:

Available reports:

COMMENTS:
1st pump lost down hole & replaced

---

his report created as part of the

PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32023

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Senelac
Array size: 810. Wp

Telephone:
No. of Systems: 1

PROJECT:

Type of Operating Load: village pump
Location: Noto,Senegal
Installation Date: 1986
Application Classification: 12.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m
Dynamic Head: m

perating Voltage: volts.
Module Manufacturer: Isofoton
otor Type:
Motor Manufacturer:
Motor Size:
Pump Type:
Pump Manufacturer:

Control Type:
Control Manufacturer:
Battery:
Array Support Structure:

Available reports: Lorenzo 7Th&*th CEC sub Sahel Village

COMMENTS:

MIDA Senegalese Min of Art.& Ind Dev. 20l/day/pers

---

his report created as part of the

PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32024

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: various ?CEL
Array size: 720. Wp
No. of Systems: 200
Telephone:

PROJECT:

Type of Operating Load: village pumping
Location: India
Installation Date: 85-88
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 9000 L/day
Static Head: m Dynamic Head: 12-15 m

erating Voltage: 48 volts. Module Manufacturer: CEL
motor Type: DC 60V Series Motor Manufacturer: belt driven
Motor Size: 1/2
Pump Type: reciprical 75mm Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: no Array Support Structure: fixed

Available reports: IEEE Poster 1988

COMMENTS:
typical system

---

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PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32025

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: various/CEL
Array size: 720. Wp
No. of Systems: 200
Telephone:

PROJECT:

Type of Operating Load: village pumping
Location: India
Installation Date: 85-88
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 9000 l/day
Static Head: 12-15 m
Dynamic Head: DC 60V Serm

erating Voltage: 144 volts.
Module Manufacturer: JPL
motor Type: ies
Motor Manufacturer: belt driven
Motor Size: 1/2
Pump Type: Reciprical 75mm
Pump Manufacturer:

Control Type:
Control Manufacturer:
Battery: no
Array Support Structure: fixed

Available reports: IEEE Poster 1988

COMMENTS:
typical system

---

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PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32026

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: various CEL
Array size: 1440. Wp

Telephone:
No. of Systems: 200

PROJECT:

Type of Operating Load: village pumping
Location: India
Installation Date: 85-88
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 18-20000 l/day
Static Head: m Dynamic Head: 12-15 m

erating Voltage: 60 volts. Module Manufacturer: CEL
motor Type: 60V DC Series Motor Manufacturer: ?
Motor Size: 1.5 hp
Pump Type: Reciprical 100mm Pump Manufacturer: ?

Control Type: Control Manufacturer:
Battery: no Array Support Structure: fixed

Available reports: IEEE '88 poster

COMMENTS:
typical CEL installation

---

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PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32027

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Nasa/village
Array size: 1800. Wp
Telephone:
No. of Systems: 1

PROJECT:

Type of Operating Load: water pumping
Location: Tangaye,Bukina Fosa Installation Date: 1978
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 4500 l/day
Static Head: 10 m Dynamic Head: m

perating Voltage: volts. Module Manufacturer:
otor Type: Motor Manufacturer:
Motor Size:
Pump Type: Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: Array Support Structure:

Available reports: NASA Tech Memo 8697C March'85

COMMENTS:
US AID project also grind mill

---

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PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32028

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Comm.Coop of Basaisa
Array size: 500. Wp
No. of Systems: 1
Telephone:

PROJECT:

Type of Operating Load: village pumping
Location: Basaisa Egypt
Installation Date: 1979
Application Classification: 11. 0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m
Dynamic Head: m

perating Voltage: volts.
Module Manufacturer:
Motor Type: DC brushless
Motor Manufacturer:
Motor Size:
Pump Type: submersible
Pump Manufacturer: SEI-15 SunPump

Control Type:
Control Manufacturer:
Battery:
Array Support Structure: trolleys

Available reports: PV Sec2 paper

COMMENTS:

---

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PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32029

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Comm Coop of Basaisa
Array size: 350. Wp
No. of Systems: 1
Telephone:

PROJECT:

Type of Operating Load: village pumping
Location: Basaisa Egypt
Installation Date: 1984
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m
Dynamic Head: m

erating Voltage: volts.
Module Manufacturer:
otor Type:
Motor Manufacturer:
Motor Size:
Pump Type: submersible
Pump Manufacturer: SEI43L SunPump

Control Type:
Control Manufacturer:
Battery:
Array Support Structure: normal tracking

Available reports: Salah Arafa

COMMENTS:

---

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PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32030

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Comm. Coop of Basaisa

Array size: 250. Wp

Telephone:

No. of Systems: 1

PROJECT:

Type of Operating Load: village pumping
Location: Basaisa Egypt
Installation Date: 1982
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m
Dynamic Head: m

perating Voltage: volts.
Module Manufacturer:
otor Type:
Motor Manufacturer:
Motor Size:
Pump Type: submersible
Pump Manufacturer: SEI-2501

Control Type:
Control Manufacturer:
Battery:
Array Support Structure: trolley

Available reports: Salah ARAFA

COMMENTS:

---

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PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32031

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: BPPT
Array size: 6300. Wp
No. of Systems: 1
Telephone:

PROJECT:

Type of Operating Load: village water
Location: Kenteng Indonesia Installation Date: 1985
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m Dynamic Head: 140m m

Operating Voltage: 240 volts. Module Manufacturer: Kyocera
Motor Type: 3 phase AC Motor Manufacturer:
Motor Size: 1.1k & .55kW
Pump Type: Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: 600AH 240V Array Support Structure: fixed

Available reports: NEDO

COMMENTS:
NEDO Sunshine Program Project

---

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PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32032

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Univ Nebraska
Agric Eng Dept
Lincoln Nebraska 68503
Telephone:

Array size:25000. Wp
No. of Systems: 1

PROJECT:

Type of Operating Load: irrigation
Location: Mead Nebraska Installation Date: 1977
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 900 gpm
Static Head: m Dynamic Head: m

perating Voltage: 120 volts. Module Manufacturer: SLX Sensor Tech
.otor Type: AC DC Motor Manufacturer:
Motor Size: 20 hp
Pump Type: Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: 90kW 120V Array Support Structure: fixed

Available reports: DOE/ET/20279-240

COMMENTS:
Largest PV system in world when installed

---

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PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32033

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Mobil Saudi Arabia
Array size: 8000. Wp

No. of Systems: 1

Telephone:

PROJECT:

Type of Operating Load: desalination RO
Location: Jeddah Saudi Arabia Installation Date: 1981
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 500 GPD
Static Head: m Dynamic Head: 850 psi m

perating Voltage: 240 volts. Module Manufacturer: Mobil Solar
otor Type: DC 240V Motor Manufacturer: various
Motor Size: 1/4 - 5hp
Pump Type: Pump Manufacturer: various

Control Type: Int.AMP Hr Control Manufacturer: Mobil Solar
Battery: yes 228V Array Support Structure: fixed

Available reports: PVSC 15th p.1219-1224

COMMENTS:
PVSC 16th p.1400-1404

---

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PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

MALI AQUA VIVA

LISTE DES POMPES SOLAIRES INSTALLÉES

(Situation au 15 Novembre 1986)

N°	VILLAGES	DATE	PANNEAUX	POMPES	REMARQUES
1	NABASSO I	07/77	SOLAR POWER 900 W	GUINARD ALT. XF	A changer
2	KONI I	08/77	FRANCE PHOT. 900 W	GUINARD ALT. XF	Remplacé par : GRUND. SP4-8
3	TOMINIAN I	01/78	ARCOSOLAR 1300 W	GUINARD F6-5	Remplacé par : GRUND. SP2-18
4	YANGASSO I	01/78	SOLAREX 1300 W	GUINARD ALT. XF	Remplacé par : GRUND.
5	SAN	09/79	PHOTOWATT 900 W	GUINARD ALT. XF	Remplacé par : GRUND.
6	YANGASSO II	11/79	SOLAREX 1300 W	GUINARD ALT. XF	Remplacé par : GRUND.
7	DJENNA	04/80	FRANCE. PHOT. 1300 W	GUINARD ALT. XF	Remplacé par : GRUND. SP2-18
8	SAFOLO	04/80	FRANCE. PHOT. 1300 W	GUINARD ALT. XF	Remplacé par : GRUND. SP2-18
9	KIMPARANA	05/80	ARCO 1300 W	GUINARD F6-5	Remplacé par : GRUND. SP2-18
10	BE	05/80	FRANCE. PHOT. 13300 W	GUINARD F6-5	Remplacé par : GRUND. SP2-18
1	KONI II	10/80	FRANCE. PHOT. 900 W	GUINARD surface	Installé à TOMINIAN
12	TION	10/80	FRANCE. PHOT. 600 W	GUINARD ALT. XF	A changer
13	BOSSONI	11/80	FRANCE. PHOT. 1300 W	GUINARD F6-5	Remplacé par : GRUND. SP2-18
14	KORO	12/80	FRANCE. PHOT. 1300 W	GUINARD ALT. XF	A changer
15	WASSARO	12/80	FRANCE. PHOT. 1300 W	GUINARD F6-5	Remplacé par : GRUND. SP2-18
16	BAN MANKALA	12/80	ARCO 1300 W	GUINARD F6-5	Remplacé par : GRUND. SP2-18
17	NDOSSO	01/81	FRANCE. PHOT. 1300 W	GUINARD ALT. FX	A changer
18	NWORO (TERYA)	03/81	FRANCE. PHOT/PHOTOW 5200 W + 5000 W	GUINARD surface (Electricité)	
19	NIOUGESSO	06/81	ARCO 1300 W	GUINARD F6-5	Remplacé par : GRUND. SP2-18
20	SINZARA	07/81	ARCOSOLAR 1300 W	GUINARD F6-5	
21	WOLONI	07/81	ARCO 1300 W	GUINARD F6-5	Remplacé par : GRUND. SP2-18
22	KOTERE	07/81	ARCO 1300 W	GUINARD ALT. XF	A changer
23	TOMINIAN II	07/81	ARCO 1300 W	GRUND. SP2-18	(05/84)
24	TIESSO	01/82	ARCO 900 W	GUINARD ALT. XF	
25	OUROUNTOUMA	02/82	PHOTOWATT 220 W	PHOTOW-Proto	Remplacé par : GRUND.
26	NTOBA	05/82	ARCO 900 W	GUINARD ALT. XF	A changer
27	TOMINIAN III	05/83	PHOTOWATT 800 W	SOFRETES surface	Remplacé par : GUINARD surface

N°	VILLAGES	DATE	PANNEAUX	POMPES	REMARQUES
28	**TIEMENA**	02/84	ARCO 1400 W	GRUND. SP2-18	
29	**DIARAMANA**	10/84	ARCO 900 W	GUINARD ALT. XF	
30	**WERU**	09/84	FRANCE. PHOT. 1400 W	GUINARD surface	
	TERIYABUGU	03/85	PHOTOWATT 1300 W	TOTAL immergée	Pépinière
32	**DOWBO**	04/85	FRANCE. PHOT. 1300 W	GUINARD immergée	GRUND. SP2-18
33	**GOUALA**	05/85	PHOTOWATT 1400 W	GRUND. SP2-18	
34	**SAN** (Ecole Baddi)	10/85	FRANCE. PHOT. 430 W	GUINARD immergée	
35	**DIAKORO**	11/85	FRANCE. PHOT. 860 W	GUINARD immergée	Total immergée
36	**KABALA**	12/85	ARCO 1400 W	GRUND. SP4-8	
37	**KEMENI I**	12/85	PHOTOWATT 1400 W	GRUND. SP2-18	
38	**NIALA**	01/86	PHOTOWATT 1400 W	GRUND. SP2-18	
39	**FANI I**	01/86	PHOTOWATT 1400 W	GRUND. SP2-18	
40	**KEMENI II** (Ecole)	02/86	ARCO-SOLAR 1400 W	GRUND. SP2-18	
41	**SANGHA**	03/86	PHOTOWATT 1400 W	GRUND. SP2-18	
42	**KIO**	03/86	PHOTOWATT 1400 W	GRUND. SP2-18	
43	**FANI II**	06/86	PHOTOWATT 1400 W	GRUND. SP2-18	
44	**TERIYABUGU** (château-d'eau)	05/86	PHOTOWATT 1400 W	GRUND. SP2-18	
45	**GOUALABOUGOU**	04/86	PHOTOWATT 1400 W	GUINARD surface	
46	**SAGARA**	06/86	PHOTOWATT 1400 W	GUINARD surface	
47	**MADIMANSO**	06/86	PHOTOWATT 1400 W	GRUND. SP2-18	
48	**NABASSO II**	11/86	PHOTOWATT 1280 W	TOTAL	Ecole et Dispensaire
49	**TERIYA BUGU-EST**	12/86	PHOTOWATT 1400 W	GUINARD surface	Verger Maraicher
50	**TIA**	01/87	ARCO 1400 W	GRUNDFOSS	
51	**TOUBA**	12/86	ARCO 1400 W	GRUND SP4-8	Ecole Verger
52	**BLA**	10/87	PHOTOWATT 1400 W	TOTAL	Ecole
53	**BLA**	10/87	PHOTOWATT 1400 W	TOTAL	Ville
54	**MPEBUGU**	02/87	PHOTOWATT 600 W	TOTAL	Elevage
55	**AROUANE**	03/87	ARCO 2000	TOTAL	Population et Caravane Chameaux Porteurs de sel

noter que lorsque l'on parle de changement ou de remplacement il ne s'agit que du système de pompage, soit en valeur le $1/10^{\text{me}}$ de la valeur totale. Les panneaux eux restent inchangés car jusqu'ici la fiabilité est parfaite.

GRUNDFOS Solar Pumping Systems. Selected References. (November 1983).

Country	Location	Purchaser	System	Installation/ Application	Supplementary information
Australia	De Vale, Ivanhoe, New South Wales	Mr. J. Harris	SP 2-18/14 modules	Stock watering, depth of 30 m, 15 m^3/day, storage tank. Installed in June 1983	Considerable interest generated in the area
Bangladesh	Dmaka	Atomic Energy Commission	SP 8-4/35 modules	Irrigation project. Installed in 1983	
France	Levallois-Perret	Total Cfd, Levallois-Perret	SP 4-8/subsystem	N/A	
	Saint Paul Les Durances	Commissariat à l'Energie Atomique	SP 4-8/subsystem	Testing procedures. Installed in 1983	
India	Bombay	Danfoss	SP 2-18/subsystem	Irrigation project at Kapur Farm	
Kenya	Mutomo	Aid Programme	SP 8-4/14 modules SP 4-8/ 7 modules	Irrigation of vegetables. Installed in 1983	
Mali	N/A	Le Père Verspien, Paris	Two systems: SP 2-18/35-4	N/A	
Oman	Salalah	Tecodev	SP 2-18/35 modules	Water supply and livestock watering in village in the mountains. Installed at the beginning of 1983	
Somalia	Sablaale	UN Organisation	SP 4-8/35 modules	Village water supply. Installed in the summer of 1983	
Spain	Formentera island	F Laborey, Paris, France	SP 2-18/Photowatt modules	N/A	The GRUNDFOS pump has replaced a Photowatt pump
Sudan	Wad Medani	Ministry of Construction	SP 4-8/28 modules	Water supply and test purposes at the University in Wad Medani. Installed in March 1983	
	Torit	Norwegian Church Organisation	6 complete systems	Water supply in Rural Development Centres in the Southern Region. Overflow used for irrigation purposes	
U. A. E.	Dubai	Khoory	SP 2-18/35 modules	Livestock watering in the desert. Installed in the spring of 1983	
	Dubai	Khoory	SP 2-18/35 modules	N/A	
	Dubai	Khoory	SP 2-18/35 modules	N/A	
Uganda	Kampala	General Machines	Two systems: SP 2-18/14 modules and SP 4-8/35-5	Installed in health clinics in the northern part of Uganda. Installed in 1983	
U.S.A	Nevada	Nevada Pump & Supply	SP 4-8/35 modules	Demonstration purposes, irrigation. Installed in June 1983	Static head 30 m. 7 m^3/h at 1.00 pm
	Utah	Delco Western	SP 2-18/21 modules	Irrigation purposes. Installed in June 1983	Static head 30 m
	Utah	Delco Western	SP 2-18/28 modules	Cattle watering. Installed in July 1983	Static head 58 m. 2.3 m^3/h at noon
	Clovis, California	Willow Gardens	SP 16-2/7 modules	Fish pond circulation. Is being erected	
Zaire	Kinshasa	Swedish Church Organisation	SP 2-18/subsystem	Village water supply. Installed at the end of 1982	
Zimbabwe	Bindura	Local farmer	SP 4-8/14 modules	Cattle watering and water supply. Installed in September 1983	Replaces windmill

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h Alberta		344 Wp	stock watering	32201
bridge,Alberta		215 Wp	stock watering	32202
h Bay,Ont		43 Wp	cottage pump	32203
e Creek B C		470 Wp	stock watering project210	32204
t Current		387 Wp	Stock watering	32205
rose Sask		250 Wp	cattle watering	32206
sHead		326 Wp	stock watering	32207
h Alberta		212 Wp	stock watering winter	32208
h Alberta		1 Wp	stack watering	32209
h Valley B C		282 Wp	water pumping	32210
h Valley		282 Wp	water pumping	32211
ies		700 Wp	stock watering	32212
au Park Ont		280 Wp	Wahroom water	32213
uver B C		350 Wp	demo	32214
	6 sites	12volt	res. water	32215
	6 sites	120 V	reidential water	32216
ridge Alberta		270 Wp	pumping demo	32217
ridge Alberta		172 Wp	pumping demo	32218
Alberta		220 Wp	water pump test	32219
ridge Alberta		258 Wp	pumping demo	32220
ld Al		212 Wp	water pumping	32221
eer pumping dem		212 Wp	o/test	32222
n		212 Wp	stock watering	32223

national via Canada
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dos	1060 Wp	water pumping	32401
ca	250 Wp	water pumping	32402
	250 Wp	pumping demo	32403
	1400 Wp	water supply	32404
al	1060 Wp		32405

Report Number: 32201

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: /Env.Systems
S.Alberta

Array size: 344. Wp

Telephone:

No. of Systems: 1

PROJECT:

Type of Operating Load: stock watering
Location: South Alberta
Installation Date: 1985
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: 55 m
Dynamic Head: m

Operating Voltage: volts.
Module Manufacturer: ARCO
Motor Type: DC
Motor Manufacturer:
Motor Size:
Pump Type: surface
Pump Manufacturer: AY MacDonald

Control Type:
Control Manufacturer:
Battery:
Array Support Structure:

Available reports:

COMMENTS:
into 5000 gal tank

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```
                                        Report Number:  32202

               ****   PV WATER PUMPING PROJECT REPORT  ****


 GENERAL:

     Owner: Prairie Animal Research Unit       Array size:  215. Wp
          Lethbridge
          Alberta                              No. of Systems:     1
          Telephone:


 PROJECT:

     Type of Operating Load: stock watering
     Location: Lethbridge,Alberta  Installation Date: 1988
     Application Classification: 11.0

               *******************************************

 SYSTEM DESCRIPTION:

 Design Volume:
 Static Head: 8         m  Dynamic Head:          m

 Operating Voltage:     volts.  Module Manufacturer: Arco
 Motor Type: DC                  Motor Manufacturer:
         Motor Size: .5hp
 Pump Type: cent.double impellorPump Manufacturer: AY MacDonald

 Control Type:                      Control Manufacturer:
 Battery:             Array Support Structure:


     Available reports:


 COMMENTS:
     from fenced ho;e to trough via ENV.SYS.



-----------------------------------------------------------------

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Report Number: 32203

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Community College
North Bay
Array size: 43. Wp

Telephone:
No. of Systems: 1

PROJECT:

Type of Operating Load: cottage pump
Location: North Bay,Ont
Installation Date: 1986
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: 10 m
Dynamic Head: m

perating Voltage: 12 volts.
Module Manufacturer: Arco
Motor Type: DC
Motor Manufacturer:
Motor Size: .2hp
Pump Type: pressure tank
Pump Manufacturer: AY MacDonald

Control Type:
Control Manufacturer:
Battery:
Array Support Structure:

Available reports:

COMMENTS:
individual tech with geotech diamond drilling

---

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Report Number: 32204

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: B C Min.of Agric. and Fisheries Array size: 470. Wp
Attn.Lance Brown
Kamloops B C No. of Systems: 1
Telephone:

PROJECT:

Type of Operating Load: stock watering project210
Location: Cache Creek B C Installation Date: 1986
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 3800 l/day
Static Head: .43 m Dynamic Head: 55m m

Operating Voltage: 180 volts. Module Manufacturer: Arco
Motor Type: DC Motor Manufacturer: D O ERR
Motor Size: 2hp
Pump Type: Rot P C Pump Manufacturer: Moyno

Control Type: MPT Control Manufacturer: Wardun
Battery: no Array Support Structure:

Available reports: EMR 73-W4-86 G128

COMMENTS:
P.Ward development unit Report EDBC 85-032 Video

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Report Number: 32205

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: PFRA
Ron Lien, Campbell
Telephone:

Array size: 387. Wp
No. of Systems: 1

PROJECT:

Type of Operating Load: Stock watering
Location: Swift Current
Installation Date: 1985 ?
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m
Dynamic Head: m

erating Voltage: volts.
Module Manufacturer: Arco
Motor Type:
Motor Manufacturer:
Motor Size:
Pump Type:
Pump Manufacturer:

Control Type:
Control Manufacturer:
Battery:
Array Support Structure: fixed

Available reports:

COMMENTS:
first PFRA demo

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Report Number: 32206

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: PFRA
Regina,Sask
Telephone: 306 780 6350

Array size: 250. Wp
No. of Systems: 1

PROJECT:

Type of Operating Load: cattle watering
Location: Montrose Sask Installation Date: May 1986
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 12IGPM actual
Static Head: ■ Dynamic Head: <20' ■

erating Voltage: 36 volts. Module Manufacturer: Arco
Motor Type: DC submersible Motor Manufacturer: ?
Motor Size: ?
Pump Type: submersible cent SMCPump Manufacturer: Jacuzzi

Control Type: none Control Manufacturer: none
Battery: none Array Support Structure: Zomework tracker

Available reports: memo by R LIen 306 780 6350... 424 210 733 0

COMMENTS:
330 cattle, Cambrian Eng design

---

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Report Number: 32207

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Brent Greig
PO Box 202
Lions Head Ont NOH 1WO
Telephone: 519 793 3792

Array size: 326. Wp
No. of Systems: 1

PROJECT:

Type of Operating Load: stock watering
Location: LionsHead
Installation Date: 1988
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 7 gpm delivery
Static Head: 17 ft m Dynamic Head: 30 ft. m

perating Voltage: 12 volts. Module Manufacturer: Arco
Motor Type: 115 Vac Motor Manufacturer:
Motor Size: 1/2hp
Pump Type: Berkeley Jet Pump Pump Manufacturer: Berkeley

Control Type: Control Manufacturer:
Battery: 9.2KwGNB12 Array Support Structure: DIHN tracker

Available reports: via Madill

COMMENTS:
Heart HF 12-2000SX DC/AC inverter

---

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Report Number: 32208

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Sears # 1
c/o Dirk & Price
Calgary, Alberta
Telephone: 403 283 4323

Array size: 212. Wp

No. of Systems: 1

PROJECT:

Type of Operating Load: stock watering winter
Location: South Alberta
Installation Date: Dec 1987
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: 5 m
Dynamic Head: m

perating Voltage: 12 volts.
Module Manufacturer: Solarex
Motor Type: DC
Motor Manufacturer:
Motor Size: 1/8 hp
Pump Type: bildge
Pump Manufacturer:

Control Type:
Control Manufacturer: Solarex
Battery: GNB Watchm
Array Support Structure: an 3

Available reports: no

COMMENTS:
winter seasonal use

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Report Number: 32209

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Sears #2
c/o Dirk & Price
Calgary, Alberta
Telephone: 403 283 4323

Array size: 1. Wp

No. of Systems: 1

PROJECT:

Type of Operating Load: stack watering
Location: South Alberta
Installation Date: Feb 1989
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: 10 m
Dynamic Head: m

Operating Voltage: 12 volts.
Module Manufacturer: Solarex
Motor Type: DC
Motor Manufacturer:
Motor Size: 1/4 hp
Pump Type: jack pump
Pump Manufacturer: Wainright

Control Type:
Control Manufacturer:
Battery:
Array Support Structure:

Available reports:

COMMENTS:
winter seasonal use

---

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Report Number: 32210

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Robin Laptuns /
General Delivery
Nemiah Valley B C VOL 1X0
Telephone: N494536Chilanko

Array size: 282. Wp
No. of Systems: 1

PROJECT:

Type of Operating Load: water pumping
Location: Nemiah Valley B C Installation Date: 1988
Application Classification: 11.03

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m Dynamic Head: m

Operating Voltage: 12 volts. Module Manufacturer: Arco
Motor Type: 12V DC Motor Manufacturer:
Motor Size:
Pump Type: piston Pump Manufacturer:

Control Type: Control Manufacturer: Photron
Battery: CB-8D-800 Array Support Structure:

Available reports: AES

COMMENTS:

via Bob Mathews AES

---

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Report Number: 32211

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Remy Williams
General Delivery
Nemiah Valley B C VOL 1X0
Telephone: N494536Chilanko

Array size: 282. Wp
No. of Systems: 1

PROJECT:

Type of Operating Load: water pumping
Location: Nemiah Valley
Installation Date: 1988
Application Classification: 3

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m
Dynamic Head: m

perating Voltage: 24 volts.
Module Manufacturer: Arco
Motor Type: 110
Motor Manufacturer: 1/3 hp
Motor Size: AC
Pump Type:
Pump Manufacturer:

Control Type: 30 amp
Control Manufacturer: Photron
Battery: CB 8D 400
Array Support Structure:

Available reports: AES

COMMENTS:
At Band office inverter causes statec

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Report Number: 32212

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: ?/Argus Telecom
c/o John McCabe
Montreal P Q
Telephone: 514 331 0840

Array size: 700. Wp

No. of Systems: 1

PROJECT:

Type of Operating Load: stock watering
Location: Prairies
Installation Date: 1987
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m
Dynamic Head: m

Operating Voltage: ? volts.
Module Manufacturer: Hoxan
Motor Type:
Motor Manufacturer:
Motor Size:
Pump Type:
Pump Manufacturer:

Control Type:
Control Manufacturer:
Battery:
Array Support Structure: mobile /

Available reports: none

COMMENTS:

McCabe unwilling to provide further data!

---

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Report Number: 32213

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Ontario Provincial Parks
c/o Kerr Solar
Chatham Ont
Telephone:

Array size: 280. Wp

No. of Systems: 1

PROJECT:

Type of Operating Load: Wahroom water
Location: Rondeau Park Ont Installation Date: 1984
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: 7 m Dynamic Head: m

erating Voltage: 120 volts. Module Manufacturer: Solarex
Motor Type: DC Motor Manufacturer:
Motor Size: 1/2 hp
Pump Type: cent Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: no Array Support Structure: roof fixed

Available reports:

COMMENTS:
summer seasonal use

---

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Report Number: 32214

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Ergo Industries
990-West Georgia
Vancouver B C V6G 3A1
Telephone: 604 658 4834

Array size: 350. Wp
No. of Systems: 1

PROJECT:

Type of Operating Load: demo
Location: Vancouver B C Installation Date: 1987
Application Classification: 15.1

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: 5 m Dynamic Head: m

erating Voltage: 90 volts. Module Manufacturer: Arco
Motor Type: DC Motor Manufacturer: ?
Motor Size: 1/3hp
Pump Type: submersible Pump Manufacturer: Ergo

Control Type: Control Manufacturer: Ergo
Battery: no Array Support Structure: fixed

Available reports:

COMMENTS:
removed 1988

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Report Number: 32215

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Various
c/o AES,RR #1,Site9,
Camp 16, CHASE, B C VOE 1MO
Telephone: 604 679 8350

Array size: 6. Wp
No. of Systems: 6

PROJECT:

Type of Operating Load: res. water
Location: B C
Installation Date: 1985-88
Application Classification: 11

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m
Dynamic Head: m

perating Voltage: 12 volts.
Module Manufacturer: various
Motor Type: DC
Motor Manufacturer:
Motor Size:
Pump Type: various
Pump Manufacturer:

Control Type:
Control Manufacturer:
Battery:
Array Support Structure: fixed

Available reports:

COMMENTS:
see reports

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Report Number: 32216

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: various
c/o AES RR #1
Site9 Camp 16, Vancouver V0E 1M0
Telephone: 604 679 8350

Array size: 6. Wp

No. of Systems: 6

PROJECT:

Type of Operating Load: reidential water
Location: B C
Installation Date: 85-88
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m
Dynamic Head: m

erating Voltage: 110 volts.
Module Manufacturer: various
Motor Type: AC
Motor Manufacturer:
Motor Size:
Pump Type: various
Pump Manufacturer:

Control Type:
Control Manufacturer:
Battery:
Array Support Structure: fixed

Available reports:

COMMENTS:
see reports

---

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Report Number: 32219

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Olds College
Olds
Alberta
Telephone: 403 556 8281
TOM 1PO

Array size: 220. Wp
No. of Systems: 1

PROJECT:

Type of Operating Load: water pump test
Location: Olds Alberta
Installation Date: 1987
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: various m
Dynamic Head: m

Operating Voltage: 12 volts.
Module Manufacturer: Arco
Motor Type:
Motor Manufacturer:
Motor Size:
Pump Type:
Pump Manufacturer:

Control Type:
Control Manufacturer:
Battery:
Array Support Structure: tracker

Available reports: no

COMMENTS:
Jensen Eng Supply

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Report Number: 32217

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Cambrian Eng Grp Ltd
519 -105 St E
Saskatoon Sask S7N 1Z2
Telephone: 306 374 8242

Array size: 270. Wp
No. of Systems: 1

PROJECT:

Type of Operating Load: pumping demo
Location: Lethbridge Alberta Installation Date: 1984
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: 5 m Dynamic Head: m

Operating Voltage: 36 volts. Module Manufacturer: Arco
Motor Type: DC Sub Motor Manufacturer: Jacuzzi
Motor Size: 1/3 hp
Pump Type: MS Cent sub Pump Manufacturer: Jacuzzi

Control Type: Control Manufacturer:
Battery: Array Support Structure: fixed

Available reports: LWRTS evaluation ERRF RP 89

COMMENTS:

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Report Number: 32218

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Environmental Systems
c/o Jim Fox, Box 370
Ingersoll N5C 3V3
Telephone: 519 485 4558

Array size: 172. Wp
No. of Systems: 1

PROJECT:

Type of Operating Load: pumping demo
Location: Lethbridge Alberta Installation Date: 1985
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: 5 m Dynamic Head: m

perating Voltage: volts. Module Manufacturer: Arco
Motor Type: DC surface Motor Manufacturer: MET
Motor Size: 1/3 hp
Pump Type: S.Stage Cent SurfacePump Manufacturer: MacDonald 810103 DJ

Control Type: Control Manufacturer:
Battery: Array Support Structure: fixed

Available reports: LWRTS Evaluation ERRF RP89

COMMENTS:

---

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Report Number: 32220

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Canadian Agtechnology Partners CAPArray size: 258. Wp
Eric Jenen
5037-50th Str. OLDS AlberTOM 1PO No. of Systems: 1
Telephone: 403 556 8779

PROJECT:

Type of Operating Load: pumping demo
Location: Lethbridge Alberta Installation Date: 1988
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: 5 m Dynamic Head: m

perating Voltage: 45 volts. Module Manufacturer: Arco
Motor Type: DC Sub Motor Manufacturer: Jacuzzi
Motor Size:
Pump Type: MS Cent Sub Pump Manufacturer: Jacuzzi SJ1

Control Type: Control Manufacturer:
Battery: Array Support Structure: tracker

Available reports: LWRTS Evaluation ERRF RP 89

COMMENTS:

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Report Number: 32221

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: F & R Towers
Array size: 212. Wp

Penhold Alberta
Telephone:
No. of Systems: 1

PROJECT:

Type of Operating Load: water pumping
Location: Penhold Al
Installation Date: July 1988
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 1.5 gpm
Static Head: 16 m
Dynamic Head: m

erating Voltage: 24 volts.
Module Manufacturer: Arco
Motor Type:
Motor Manufacturer:
Motor Size:
Pump Type:
Pump Manufacturer:

Control Type:
Control Manufacturer:
Battery:
Array Support Structure: zomework

Available reports:

COMMENTS:
Zomework tracker

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                                             Report Number:  32222

               ****   PV WATER PUMPING PROJECT REPORT  ****


  GENERAL:

      Owner: Jensen Eng Ltd                       Array size:  212. Wp
            Olds Al
                                          TOM 1PO     No. of Systems:     1
            Telephone: 403 556 8755


  PROJECT:

      Type of Operating Load: o/test
      Location: Red Deer pumping demInstallation Date: 1988
      Application Classification: 11.0

                ***********************************************

  SYSTEM DESCRIPTION:

  Design Volume:
  Static Head: 10         m  Dynamic Head:           m

   perating Voltage: 12  volts.  Module Manufacturer: Arco
  Motor Type:                     Motor Manufacturer:
              Motor Size:
  Pump Type:                     Pump Manufacturer:

  Control Type:                      Control Manufacturer:
  Battery: no         Array Support Structure: Zomeworks


      Available reports:


  COMMENTS:




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Report Number: 32223

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: /Alberta Ag.
Olds Alberta
TOM 1P0
Telephone: 403 556 8755

Array size: 212. Wp
No. of Systems: 1

PROJECT:

Type of Operating Load: stock watering
Location: Bowden
Installation Date: 1988
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m
Dynamic Head: m

perating Voltage: 12 volts.
Module Manufacturer: Arco
Motor Type:
Motor Manufacturer:
Motor Size:
Pump Type:
Pump Manufacturer:

Control Type:
Control Manufacturer:
Battery:
Array Support Structure: Zomeworks

Available reports:

COMMENTS:

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Report Number: 32401

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Barbados Wildlife Preserve
Jean Beaulu
c/o Jensens Eng. OLDS A1 TOM 1PO
Telephone: 403 556 8755

Array size: 1060. Wp
No. of Systems: 1

PROJECT:

Type of Operating Load: water pumping
Location: Barbados
Installation Date: 1988
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 3000 211DJ/180851DK
Static Head: 200 m
Dynamic Head: m

Operating Voltage: 84 volts.
Module Manufacturer: Arco M55
Motor Type: DC
Motor Manufacturer: MacDonald/Pacific Sc
Motor Size: 1 Kw
Pump Type: 4" submersible
Pump Manufacturer: AY MacDonald

Control Type: no
Control Manufacturer:
Battery: no
Array Support Structure: fixed

Available reports:

COMMENTS:

Barbados Wildlife Reserve via CAP/Env.Sys.

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Report Number: 32402

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: ?/ Cambrian Eng
c/o Middleton

Telephone: 306 374 8242

Array size: 250. Wp

No. of Systems: 1

PROJECT:

Type of Operating Load: water pumping
Location: Jamaica
Installation Date: 1985
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m
Dynamic Head: m

perating Voltage: volts.
Module Manufacturer: Arco
Motor Type: DC
Motor Manufacturer:
Motor Size:
Pump Type: sub
Pump Manufacturer: Jacuzzi

Control Type:
Control Manufacturer:
Battery:
Array Support Structure: fixed

Available reports:

COMMENTS:

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Report Number: 32403

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Alcan /Cambrian
c/o S Miidleton

Telephone: 306 374 8242

Array size: 0. Wp

No. of Systems: 1

PROJECT:

Type of Operating Load: pumping demo
Location: India
Installation Date: 1987
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m Dynamic Head: m

perating Voltage: volts. Module Manufacturer: Arco
Motor Type: DC Motor Manufacturer:
Motor Size:
Pump Type: M S Sub Pump Manufacturer: Jacuzzi

Control Type: Control Manufacturer:
Battery: Array Support Structure: fixed

Available reports:

COMMENTS:
held in customs

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his report created as part of the

PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32404

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Lenbrook
c/o Eric Kalbach

Array size: 1400. Wp

Telephone: 416 831 6333

No. of Systems: 1

PROJECT:

Type of Operating Load: water supply
Location: Zaire
Installation Date: 1987
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume: 6000 US G/day
Static Head: 56 m
Dynamic Head: m

perating Voltage: volts.
Module Manufacturer: Solarex
Motor Type:
Motor Size:
Motor Manufacturer:
Pump Type: Sub V T
Pump Manufacturer:

Control Type:
Control Manufacturer:
Battery:
Array Support Structure:

Available reports:

COMMENTS:
Hospital survey

This report created as part of the

PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32405

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: TPK/
c/o Dr Raye Thomas

Telephone:

Array size: 1060. Wp

No. of Systems: 1

PROJECT:

Type of Operating Load:
Location: Senegal
Installation Date: 1986
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: 50 m
Dynamic Head: m

perating Voltage: volts.
Module Manufacturer: TPK
Motor Type:
Motor Manufacturer:
Motor Size:
Pump Type:
Pump Manufacturer:

Control Type:
Control Manufacturer:
Battery:
Array Support Structure:

Available reports:

COMMENTS:
see TPK report

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is report created as part of the

PV WATER PUMPING TECHNICAL STATUS REPORT - DEC.1988

by ADKINSON and ASSOCIATES

Report Number: 32408

**** PV WATER PUMPING PROJECT REPORT ****

GENERAL:

Owner: Canadian Baptist Overseas Mission Array size: 250. Wp
Bob Swann,246 Roy Ave
Penticton B C V2A 7W4 No. of Systems: 1
Telephone: 604 492 0664

PROJECT:

Type of Operating Load: irrigation
Location: Kenya Installation Date: 1984
Application Classification: 11.0

****

SYSTEM DESCRIPTION:

Design Volume:
Static Head: m Dynamic Head: m

erating Voltage: volts. Module Manufacturer:
Motor Type: Motor Manufacturer:
Motor Size:
Pump Type: Pump Manufacturer:

Control Type: Control Manufacturer:
Battery: Array Support Structure:

Available reports:

COMMENTS:
diesel added to irr 40-50 acres 4x6 panel ?

APPENDIX E

LIST OF RESOURCE CENTRES FOR RENEWABLE ENERGY SOURCES AND THE APPLICATION OF SMALL SCALE WATER SUPPLY SYSTEMS

APPENDIX E

SOURCES OF INFORMATION ON RENEWABLE ENERGY SOURCES AND THE APPLICATION FOR SMALL-SCALE WATER SUPPLY SYSTEMS

D.1 National Organizations

Algeria

Organisme National de la Recherche Scientifique
Station de l'Energie Solaire
Route de l'Observatoire
Bouzareah
Alger

Argentina

Centro de Estudios Fotointeticos y Bioquimicos
Fundacion Miquel Lillo
Universidad Nacional de Rosario
Suipacha 531
2000 Rosario

Grupo de Energie Solar
Universidad Nacional
4400 Salta,
Buenos Aires

Australia

Appropriate Technology Development Group
20 Holdsworth Street
Woolahara, NSW 2025

Australian Wind Energy Association
P.O. Box 1965
Canberra City, ACT 2601

Commonwealth Scientific and Industrial Research Organization
P.O. Box 225
Dickenson, ACT 2602

Belgium

Appropriate Technology for Developing Countries
Blyde Inkomststraat 9
B-3000 Leuven

Collectif d'Echanges pour la Technologie Approprieé
18 rue de la Sablonniere
B-1000 Brussels

Bolivia

Instituto de Energia
Academy of Sciences
Casilla 5279
La Paz

Botswana

Botswana Technology Centre
Private Bag 0092
Gabarone

Rural Industries Innovation Centre
P.O. Box 138
Kanye

Brazil

Laboratory of Solar Energy
University Campus
Paraiba Federal University
Joao Pessoa
58000 Paraiba

Technology Center of Minas Gerais
Avenida Jose Candido da Silveira 2000
P.O. Box 2306
Belo Horizonte, Manas Gerais

Burkina Faso

Centre Interafricain d'Etudes Hydrauliques
B.P. 369
Ouagadougou

Burundi

Groupe de Recherches d'Utilisation des
Energies Alternatives
Université de Burundi
Faculté des Sciences
B.P. 2700
Bujombara

Cameroon

Unité de Recherches Energetique de l'Onarest
B.P. 4110
Yaoundé

Canada

Brace Research Institute
McDonalds College of McGill University
P.O. Box 900
Ste. Anna de Bellevue, Quebec H9X ICO

International Development Research Centre
P.O. Box 8500
Ottawa KIG 3H9

Chile

Solar Energy Program
Institute of Technological Research
P.O. Box 667
Santiago

China

Beijing Institute of New Technology Applications
(People's Republic)Shi Zhi Men
Beijing

Guangzhou Institute of Energy
Conversion Technology
Chinese Academy of Science
81 Martyrs' Road
C.P.O. Box 1254
Guangzhou

Zhejiang Research Institute for Biogas and Solar Energy
Hangchow, Zhejiang

Colombia

Institute for the Development of Renewable Natural Resources
Carrera 14, No. 25 A-66
Bogota, D.E.

Las Gaviotas Centre
Apartado Aereo 18261
Bogota, D.E.

Costa Rica

Renewable Energy Resources Programme
Centro Agronomico Tropical de Investigacion
Apartado 74
Turrialba

Instituto Technologico de Costa Rica
Centro de Informacion Technologica
Apartado 159
Cartago

Ecuador

Instituto Nacional de Energia
Stam Prisca 233
Quito

Egypt

Solar Energy Laboratory
National Research Centre
El Tahrir St
Dokki, Cairo

University of Alexandria
Faculty of Engineering
Solar Application Laboratory
El-Hadara, Alexandria

Ethiopia

Ethiopian National Energy Commission
P.O. Box 486
Addis Ababa

National Water Resources Commission
P.O. Box 1008
Addis Ababa

Fiji Islands

Institute of Natural Resources
University of the South Pacific
P.O. Box 1168
Suva

France

Agence Française pour la Maitrise de l'Energie
Immeuble "Le Bearn"
27 rue Louis Vicat
75015 Paris

Groupement pour l'Exploitation
Rationelle de l'Energie Solaire
Université de Provence
Centre de Saint Jerôme
13397 Marseille

Groupe de Recherches et d'Echanges
Technologiques
30, rue de Charonne
75011 Paris

Institut Technologique Dello
Le Moulin Rouge
60410 Verberie

Gabon

Ministère de l'Energie et des Resources
Hydrauliques
B.P. 874
Libreville

Germany

German Solar Energy Industrial Association
(Federal Republic)
Kruppstrasse 5
D-4300 Essen

Bremen Overseas Research and Development Association
Bahnhofplatz 13
2800 Bremen

German Appropriate Technology Exchange
Postfach 5180
D 6236 Eschborn

Ghana

Council for Scientific and Industrial Research
P O Box 74
Kade

Technology Consultancy Centre
University of Science and Technology
Kumasi

Greece

National Council for Energy Research
P O Box 5568
Athens

Guatemala

Central American Research Institute for
Industry
P O. Box 1552
Guatemala City

Honduras

Rural Technology Programme
Apartado Postal 703
Tegucigalpa, D.C

India

Birla Institute of Technology and Science
Pilani, Gobar Research Station
Ajitmal, Etawah, U P

Central Power Research Institute
P O Box 1242
Bangalore, Karnataka 560012

Centre for Rural Development and Appropriate Technology
Haus Khnas
New Delhi 110016

Khadi and Village Industries Commission
Gobar Research and Development Centre
Kora Gramadyog, Kendra
Bombay 400 092

Indian Institute of Technology
Powai, Bombay 400 076

National Aeronautical Laboratory
Wind Power Division
P.O Box 1779
Bangalore 560 017

Tata Energy Research Institute
Bombay House
24 Homi Mody Street
Bombay 400 023

Indonesia

Dian Desa
Jl. Kali Urang Km 7
P O Box 19
Bulaksumur

Institute of Technology Bandung
Development Technology Centre
Jl. Ganesha No. 10
P O Box 276
Bandung

Solar Energy Research Centre
Gajah Mada University
Sekip Unit III
Yogjakarta

Israel

Applied Research Institute
Ben Gurion University
P O Box 11025
Beersheva 814120

Scientific Research Foundation
P O Box 8745
Jerusalem 991036

Italy

Fiat Energy Sector
Renewable Energy Systems
Via Cuneo 20
10152 Turino

International School on Solar Energy and other Ren
Energy Resources
P O Box 65
61029 Urbino

Japan

Government Industrial Research Institute
Solar Research Laboratory
1, Hirate Machi, Kita-Ku
Nagoya 1462

Jordan
Royal Scientific Society
P.O. Box 4014
Amman

Korea
Appropriate Technology Centre
(Republic of)Umwol-ri, Hongdong-myum
Hongseong-gun
Chungnam 350-11

Rural Energy Resources Division
Office of Rural Development
Institute of Agricultural Sciences
Suweon

Kuwait
Kuwait Institute for Scientific Research
P.O. Box 24885
Safat, Kuwait City

Libya
Centre for Solar Energy Studies
P.O. Box 8004
Tripoli

Madagascar
Polytechnic Institute
University of Madagaskar
B.P. 1500
Antananarivo

Mali
Centre de Recherches Solaires
B.P. 134
Bamako

Mexico
Mexican Institute of Renewable Resources
Avenida Dr. Vertiz 724
Mexico City

Nepal
Research Centre for Applied Science and Technology
Tribhuvan University
Kirtipur, Katmandu

New Zealand
Centre for Scientific and Industrial Research
Charles Ferguson Building
Bowen Street
Wellington

Niger
ONERSOL
l'Office de l'Energie Solaire
B.P. 621
Niamey

Pakistan
Appropriate Technology Development Organization
1-B Street 47th, F-7/1
Islamabad

Pakistan Council for Scientific and Industrial Research
Press Centre, 2nd Floor
Shahra-e-Kamal Ataturk
P.O. Box 672
Karachi 0109

Papua New Guinea
Papua New Guinea University of Technology
P.O. Box 793
Lae

South Pacific Appropriate Technology Foundation
P.O. Box 6937
Boroko

Philippines
Centre for Non-Conventional Energy Development
PNPC Complex
Merritt Road, Fort Bonifacio
Metro Manila

National Institute of Science and Technology
625, Pedro Gill Street, Ermita
Metro Manila

Rwanda
Université Nationale de Rwanda
Centre d'Etudes et d'Applications de l'Energie
B.P. 117
Butare

Senegal
Centre d'Etudes et de Réalisation pour les Energies Renouvables
B.P. 476

Dakar
Societé Industrielle des Applications de l'Energie Solaire
B.P. 1277
Dakar

Sierra Leone
Advisory Unit for Technology Research and Development
Faculty of Engineering
University of Sierra Leone
Mount Aureol, Freetown

Sri Lanka

Water Resources Board
Wind Energy Unit
2A Gregory's Avenue
Colombo 7

Sudan

National Council for Research
Institute of Energy Research
P.O. Box 2404
Khartoum

Suriname

University of Suriname
Department of Engineering
University Complex, Building II
Leyweg
Paramaribo

Sweden

Swedish National Board for Energy Source
Development
P.O. Box 1103
S-16312 Spanga

Swedish Agency for Research Cooperation with
Developing Countries (SAREC)
Birger Jarlsgatan 61
S 10525 Stockholm

Switzerland

SKAT
Swiss Centre for Appropriate Technology
Varnbuelstrasse 14
CH-9000 St Gallen

Tanzania

Arusha Appropriate Technology Centre
P.O. Box 764
Arusha

Thailand

Asian Institute of Technology
Renewable Energy Resources Information Centre P.O. Box
2754
Bangkok

Khon Kaen University
Faculty of Engineering
Solar Energy Group
Khon Kaen

King Mongkut's Institute of Technology
Thonburi Campus
Bangkok 14

National Energy Administration
Energy Research Section
Wind Energy Unit
Pibultham Villa
Kasatsuk Bridge
Bangkok 5

The Netherlands

Centre for International Cooperation and
Appropriate Technology
Delft University of Technology
P.O. Box 2350
Delft

Consulting Services Wind Energy Developing
Countries
P.O. Box 85
3800 AB Amersfoort

TOOL Foundation
Mauritskade 61
1092 AD Amsterdam

Togo

Solar Energy Department
School of Sciences
University of Benin
B.P. 1515
Lome

Tunisia

Association pour le Developpement et
l'Animation Rurale
10 rue Eve Nohelle
Tunis

Turkey

Turkish Solar Energy Institute
P.O. Box 37
Bakanliklar, Ankara

Power Machinery Department
Faculty of Agriculture
University of Anakara
Cengiz Sotah No. 119/3
Yeninahalle, Ankara

United Kingdom

Intermediate Technology Development Group
Myson House
Railway Terrace
Rugby CV21 3HT

IT Power Ltd.
Mortimer Hill
Mortimer, Reading, Berks. RG7 3PG

National Centre for Appropriate Technology
Llyngwern Quarry
Machynlleth
Powys, Wales

University of Reading
Energy Group
Whiteknights
Reading, Berks. RG6 1A7

United States of America

Wind Energy Association
America1609 Connecticut Avenue
Mount Rainier, Maryland 20822

IT Power Inc.
1015, 18th Street, N.W.
Suite 801
Washington, D.C. 20036

National Academy of Sciences
Board on Science and Technology for
International Development
2101 Constitution Avenue
Washington D.C. 20418

National Center for Appropriate Technology
P.O. Box 3838
Butte, Montana 59702

New Alchemy Institute
237 Hatchville Road
East Falmouth, Massachusetts 02536

Peace Corps
906 Connecticut Avenue, N.W.
Washington D.C. 20525

Sandia National Laboratories
Division 621
P.O. Box 5800
Albuquerque, New Mexico 87185

Volunteers in Technical Assistance
P.O. Box 12438
Arlington, Virginia 22209

Zambia

Technology Development and Advisory Unit
University of Zambia
P.O. Box 32379
Lusaka
Zambia

D.2 INTERNATIONAL ORGANIZATIONS

FAO

Food and Agricultural Organization of the
United Nations
Via delle Terme di Caracalla
00100 Rome
Italy

IRC

International Reference Centre for
Community Water Supply and Sanitation
P.O. Box 93190
2509 AD The Hague
The Netherlands

UNESCO

United Nations Education and Science Organization
UNESCO Network on Renewable Energy Sources
7 Place de Fontenoy
75007 Paris
France

UNICEF

United Nations Children's Fund
Water and Environmental Sanitation
Advisory Team
866 U.N. Plaza
New York, N.Y. 10017
USA

UNIDO

United Nations Industrial Development Organization
P.O. Box 2300
A-1180 Vienna
Austria

UNCNRET

United Nations Centre for Natural
Resources, Energy and Transport
1 U.N. Plaza
New York, N.Y. 10017
USA

UN/ESCAP	United Nations Economic and Social Commission for Asia and the Pacific Sala Santitham Rajdamnern Avenue Bangkok 2 Thailand
UN/ECAF	United Nations Economic and Social Commission for Africa Africa Hall P O Box 3005 Ethiopia
UN/ECLAC	United Nations Economic and Social Commission for Latin America and the Caribbean Edificio Naciones Unidas Avenida Dag Hammerskjold Casilla 179 Santiago Chile